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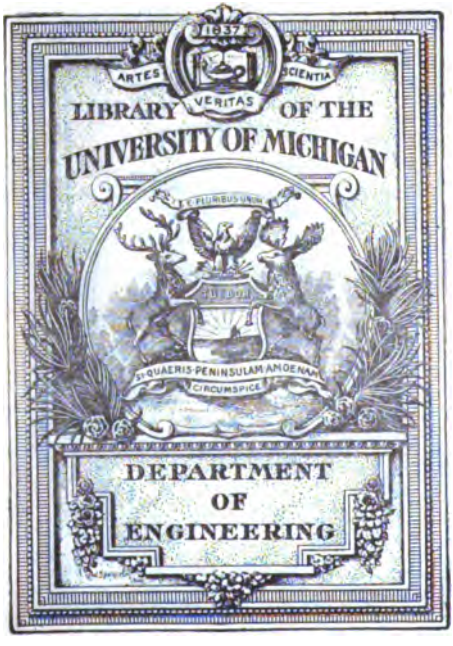
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PREFACE.

THE present volume has been prepared from the notes of lectures given by the authors to students in the School of Architecture at the Regent Street Polytechnic, during the past twenty years. Much of the subject-matter is contained in their works on Building Construction, but it has here been correlated, revised, and extended, so as to present in the form of a text-book all such information upon Brickwork and Masonry as is required by students who are making these subjects a special study.

Among the more important branches dealt with are the following: The Planning of Drains, the Building of Revetments, the Construction of Domes, Vaults, Bridges, and Skew Arches, also the Planning of Flues, Fireplaces and Tall Chimneys (so far as these concern the Bricklayer and Mason). In these subjects are involved problems, which, in the not far distant past, presented well-nigh impassable barriers to the minds of many practical workmen. Although the attempt has been here made to deal with these in a clear and concise manner, the aid of mathematics has often to be called in. Such, however, are the intellectual requirements in students of the science of building to-day that some knowledge of mathematics is

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indispensable to them, and it may be hoped they will not find any difficulty in understanding the principles of construction here set forth, nor lack the practical skill to put them into execution.

The authors beg to thank their colleagues, Messrs. T. Hobart Pritchard and A. E. Holbrow, for their help so readily given in the production of this work.

C. F. MITCHELL.

REGENT STREET POLYTECHNIC,
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January, 1904.

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BRICKWORK AND MASONRY.

CHAPTER I.

FOUNDATIONS.

Definition.—The bases of walls, piers, columns, etc., directly supported or kept in equilibrium by the earth, are known as the foundations.

Necessity for Foundations.—Walls of buildings resting on ground of variable strength often fracture, due to the unequal settlement of the work. To prevent failure in this manner, the base of the walls of the building may be extended and supported by suitable foundations.

The object of foundations is to prevent inequality of settlement, and distribute the weight of the structure equally over the substratum.

The bases of structures are invariably made wider than the superincumbent mass to increase the stability and to counteract all the following damaging forces that tend to cause failure.

Damaging Forces.—The principal causes of failure are those which induce settlement, such as inequalities of earth resistance; the compressibility of mortar joints; lateral escape of soft soil; sliding of the substratum on sloping

ground; the withdrawal of water; distributed lateral pressures, causing overturn, such as wind pressure, and thrust of barrel vaulting or of an untied couple raftered roof; concentrated lateral pressure which induces settlement and overturn, such as the thrust of framed floors, trussed roofs and groined vaults subjecting small areas of support to great pressures.

Inequality of Settlement.—Inequality of settlement in buildings takes place from two causes—(1) the compressibility of the mortar joints; (2) the compressibility of the soil.

An allowance of 1 inch in 24 feet of brickwork in lime mortar is often provided for settlement, as in the example of the extremities of bridging joists of floors, at one end being supported by a brick wall, and the other extremities by iron columns, etc.

Nearly all soils, with the exception of solid rock and gravel, are compressible under pressures often attained in buildings. It is therefore impossible, where large buildings are erected on other soils, to avoid settlement; and the fact of any building settling is of no great import, provided the settlement be uniform and of no great depth, and the relative position of the parts of the structure unaltered. But where the resistance of the soil of every part of the site is not uniform, there is a risk of the above defect occurring, and special precautions must be taken to distribute the pressure to suit the varying strengths of the substratum.

Lateral Escape.—Heavy structures erected upon soft soils, such as running sands and peat, squeeze out from beneath the foundation, unless means are taken to confine the soil to the required area; this is usually accomplished by sheet piling, as described later.

Sliding.—This is a defect usually occurring where the building is erected on the slope of a hill, and the strata

inclined, being depressed in the direction and towards the bottom of the slope. The weight of the building is liable to cause the strata to become detached and slide. This is prevented in two ways—(1) by driving piles at intervals to a considerable depth, thus connecting the strata: this method is often objectionable, tending as it does to shake and disturb the soil; (2) by building a retaining wall; this is the better method, as it not only supports, but also protects the strata from the effects of the atmosphere, which in soils easily affected by the latter is a desideratum.

Withdrawal of Water from Foundation Earth.—Edifices built on damp soil, such as a sand overlying a clay, have their stability endangered should the water be drained away after the building has been erected, as it will cause the foundation earth to occupy a less volume and in the sinking will tend to fracture or overturn the walls; therefore the depth of the concrete foundation must be arranged below any probable adjacent cutting.

Distributed Overturning Pressures.—Distributed forces acting upon the upper level of walls, such as the continuous pressure of barrel vaulting and the spreading tendencies of untied couple raftered roofs, and also the distributed pressures on wall faces, such as wind pressure, tend to cause failure in two ways—(1) by overturning, the minimum resistance being generally at the change of section usually at the ground level; (2) by subjecting the leeward edge of the wall to the pressure sufficient to crush the material or by throwing the weight on a small area of the substratum, forcing it from its original position and causing a settlement.

The stability of walls when subjected to such distributed overturning pressures is treated in the chapter on that subject.

Concentrated Lateral Pressure.—The thrust caused by untied principals or groined vaults or other forces acting at

a point or along vertical lines on the wall are often resisted by buttresses.

Atmospheric Action.—Many otherwise thoroughly reliable soils are practically reduced to the condition of mud if exposed to the effects of the atmosphere or to rain-water. The variation in temperature at the different seasons also causes the ground to expand and contract considerably.

Where foundations are constructed in such soils, they must be taken sufficiently deep to be beyond the effects of the atmosphere, that is below the line of saturation. Four feet below the ground level is usually sufficient for this purpose, the soil below this not being affected to any appreciable extent by the percolation and subsequent freezing of rain-water.

The line of saturation in the section of any part of the earth's crust represents the depth to which the soil at that part is saturated by the absorption of rain-water, and affected by atmospheric changes.

Excavations.—Before commencing any constructional work in connection with a building it is necessary as the first operation to carefully take the levels of the site, in order first to arrive at an estimate of the amount of earth-work to be done; and secondly, to determine the design of the basement story, this latter often being materially affected if the differences in level of the various parts of the site are great. The next operation is to level the ground. This in most instances consists in excavating and removing parts of the site, and in depositing earth in other parts to form embankments or to fill up hollow places. In order to conduct these operations in the most economical manner the levels must in all instances be taken and plotted with the greatest accuracy. This can only be efficiently done on areas of any magnitude by means of the surveyor's level, the method of employing which will be described later. All levelling operations for ordinary constructional

work may be carried out by referring them to the principles laid down for performing the three following operations :—

1. Taking levels of site.

2. Levelling the bottoms of trenches for drains or foundations.

3. Embanking for roads or levelling of depressions.

Instruments.—The instruments required to determine the levels of the site are—first, the surveyor's level; second, the measuring staff; third, ranging poles, and chain or tape.

Methods of Levelling.—Taking the levels of a site may be carried out in one of three ways—first, by taking a number of section lines across the site; secondly, by erecting the level in a commanding position and taking the relative heights of the salient points and noting them on plan (this method is only applicable for small sites); thirdly, by contours.

In all three methods it is necessary to have a datum level to commence from, and from which all other levels can be referred. A line on some permanent structure in the immediate vicinity is usually taken, or if such does not exist, a stout stake is driven in the ground in a position away from the work where it is not likely to be disturbed.

First Method.—A number of sections are ranged across the site, each line being numbered or lettered; the level is then set up, on or in close proximity to the first line and the datum; the measuring staff is then held by an assistant on the datum point and then on the extremity of the line, the relative heights of the two points being recorded in a field book kept for that purpose. A number of points on the line are then taken, and the measuring staff is held over them, and their relative heights are recorded, and their distances from the beginning of the line are measured. When the bottom of the measuring staff rises above, or the top becomes depressed below the line of sight,

through the rise or depression of the ground, the level must be moved further along the line and the preceding operations repeated. Figure 1 illustrates the method. The following is a form of field-book with the readings for a section entered :—

FIELD LEVEL BOOK.

Back Sight.	Inter. Sight.	Fore-Sight.	Rise.	Fall.	Reduced Levels.	Distance.	Total Distance.	Remarks.
						chains.		
4·15	...	...	...	...	100·0	...	...	Bench Mark A
	4·13	...	·02	...	100·02	1	...	1 peg
	5·01	...	...	·88	99·14	2	...	2
	4·86	...	·15	...	99·29	3	...	3
	6·06	...	...	1·20	98·09	4	...	4
		8·02	...	1·96	96·13	5	...	5
12·25								
	8·46	...	3·79	...	99·92	6	...	6
	3·04	...	5·42	...	105·34	7	...	7
		2·15	·89	...	106·23	7·57	...	Bench Mark B
12·60								
	7·19	...	5·41	...	111·64	8·57	...	8
		2·53	4·66	...	116·30	9·57	...	9
9·37								
	5·75	...	3·62	...	119·92	10·57	...	10
		3·94	1·81	...	121·73	11·57	11·57	Bench Mark C
			25·77	4·04	21·73			
			4·04					
			21·73					

The above shows a typical field level book. The reduced level of the first point is taken as 100 feet above a datum level; the levels are all read in feet and hundredths of a foot; the distances are taken in chains and links, but may be taken in feet and inches. The rise and fall columns should be balanced, also the first and last reading in the

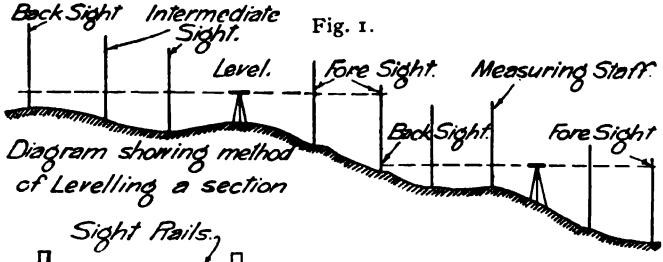


Fig. 1.

Diagram showing method of Levelling a section

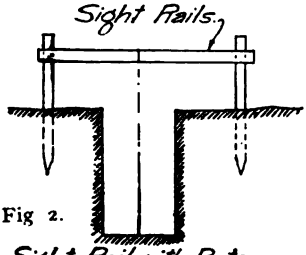


Fig 2.

Sight Rail with Posts fixed in ground.

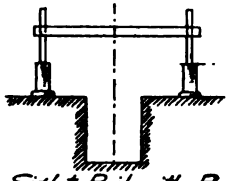
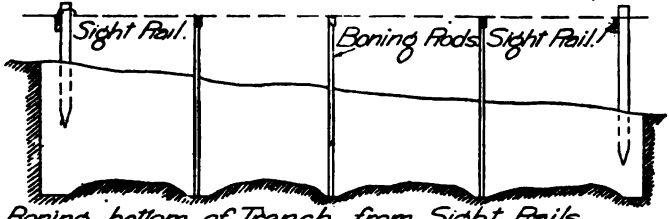


Fig. 3

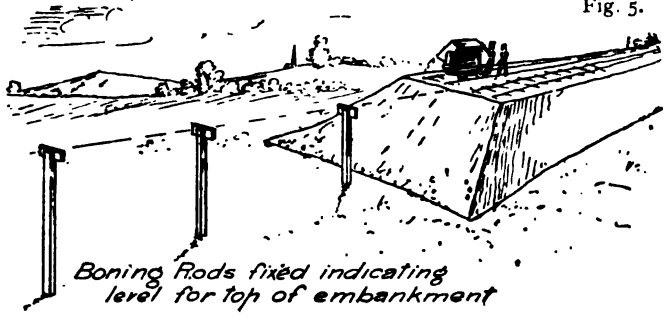
Sight Rail with Posts fixed in drain pipes

Fig. 4.



Boning bottom of Trench from Sight Rails.

Fig. 5.



Boning Rods fixed indicating level for top of embankment

reduced levels; these two quantities will equal each other if the computations have been correctly made.

Second Method.—The second method is evident from the previous explanation.

Third Method.—The method of contouring is the most useful, but takes the longest time to perform it; it consists in describing upon a plan a series of level lines with a uniform vertical interval between them. To carry out this operation it is usual to erect the instrument on the highest point of any section of the area to be contoured, and from this point to range a number of lines radiating from it, their direction being fixed by taking their bearings. The height of the instrument is then taken, and the man with the measuring staff is directed up or down each line in succession until a number of points of the required vertical interval and their distances from the initial point are determined. This method is most useful for laying out large estates where extensive works are projected, as on such a plan the problems of drainage and roads of convenient and economical gradients can easily be laid down.

When the levels of a site are known, and the building is planned, and the position of one of its leading lines is determined, to set out the remaining lines of an ordinary building becomes a simple matter, only requiring great care in the measurements of the parts. If the setting out is rendered difficult through differences of level in the parts, a theodolite would very much simplify the operations.

Boning Method of Levelling.—This operation is used for the levelling of trenches, ground work, paving, etc. There are three rods in a set, two of these are levelled at a distance of about 10 feet apart; a third rod is then levelled at a similar distance, taking care to reverse the long level. The centre rod is then removed, and the level transmitted to any point along the line by sighting or boning over the first and third rods.

Figure 6 shows the method of using boning rods and setting a kerb-stone.

Trenching.—When the lines of the building have been laid down and all its salient angles pegged out, the work of excavating the trenches commences. It is absolutely necessary that the trenches should be level along their bottoms. To ensure this two or more sight rails (as shown in Figures 2 and 3) are erected over the trench; it is necessary that the side posts of these should be fixed in

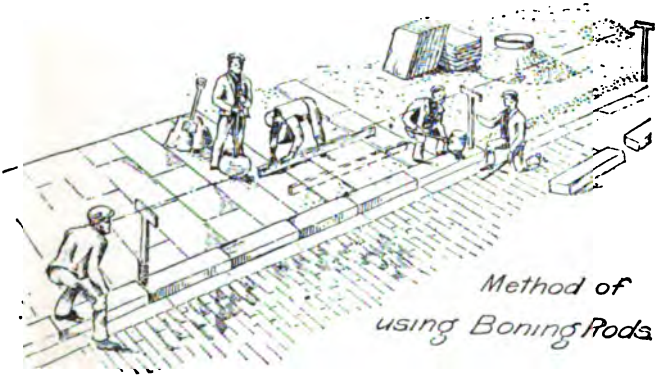


Fig. 6.

such a position that they shall not be disturbed by any of the subsequent operations. A level line is sighted through, the level and marked on the sight rails; the cross bar is then fixed on each, and a mark is made on the bars plumb over the centre of the trench. The width of the trench is marked out with the line and pins, see page 94, and the excavation is carried on, timbering being inserted as the earth is removed if required, by one of the methods afterwards described. When the full depth of the trench has been nearly reached, a number of points are sunk to

the exact depth by means of boning rods, the top of which is sighted between two of the sight rails, as shown in Figure 4. The remaining parts of the trench bottom are then taken out level between the points so determined. A similar process is pursued for sinking a trench for a drain, the variation being that the sight rails have a difference in height necessary to give the required fall.

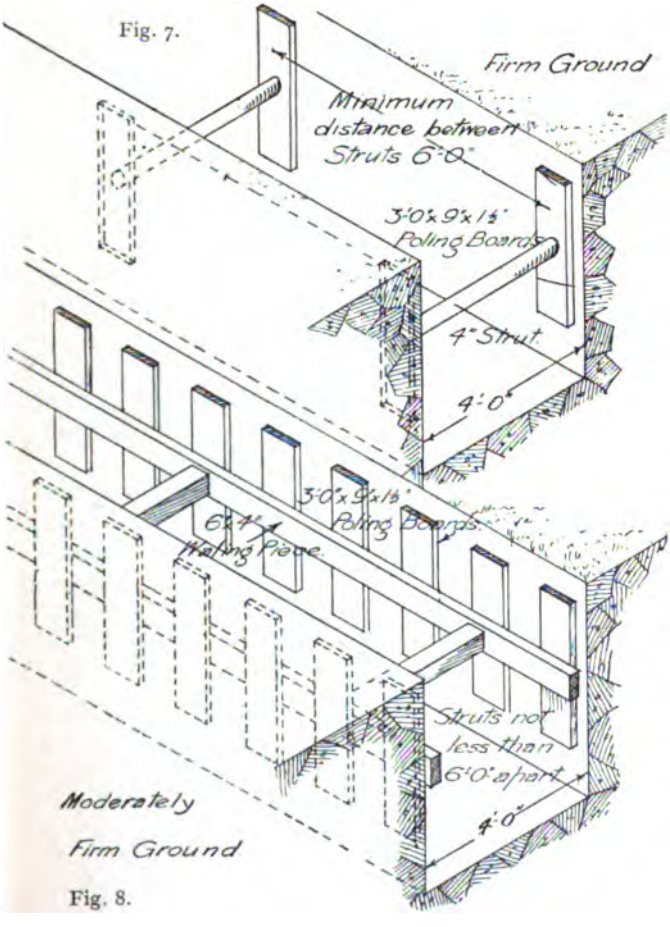
Embanking.—The method of forming an embankment is as follows:—The centre line of the proposed work is ranged out on the ground, and at equal intervals along the line boning rods are erected, the two extreme rods being first fixed either level or with a difference in height sufficient to give the required gradient; a rod is then erected on each of the intervals determined upon, and boned between the two extreme rods. The embankment is then commenced from one end, the earth being tipped in from carts or waggons until the tops of the boning rods are reached, sufficient earth in excess must be allowed for to compensate for compression and settlement. The width of the embankment is completed as the work is pushed forward, as shown in Figure 5.

Timbering for Excavations.—It becomes necessary, where earth has to be excavated to any considerable depth, for foundations or other purposes, to support the sides of the cutting until the sinkings or trenches are filled in, or other action taken to permanently support the sides. This end is attained by means of timber shores, the arrangement of which is modified and governed by several conditions, such as the nature of the soil, the size of the cutting, and the special peculiarities of the particular piece of work under consideration.

There are three typical methods of strutting used for supporting the sides of narrow trenches excavated for foundations or drainage work, shown in Figures 7 to 10.

The first, used for firm ground, consists of short upright

members, termed poling boards, out of 9 in. × 1½ in. usually from 3 to 8 feet long, placed in position in pairs,



one board on each side of the cutting; these are kept apart by struts out of about 4 in. × 4 in., or short ends of scaffold

Fig. 9.

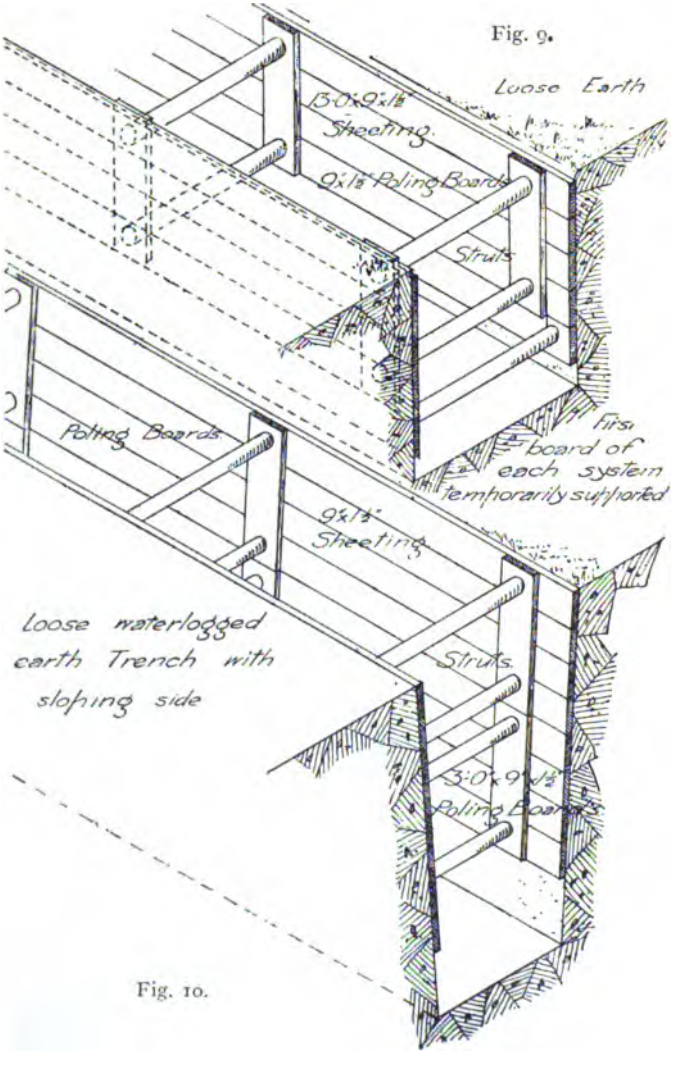

Loose Earth
13'0"x9"x1½"
Sheeting.
9"x1½" Poling Boards
Struts
Poling Boards
First board of each system temporarily supported
9"x1½"
Sheeting
Loose waterlogged earth Trench with sloping side
Struts
3'0"x9"x1½"
Poling Boards

Fig. 10.

poles cut and driven tightly between the poling boards. The strutting is fixed as soon as the trench has been made sufficiently deep. The horizontal distance apart between the adjacent systems of strutting varies according to the cohesive strength of the soil, but never less than 6 feet, which is just sufficient to allow a man to work in with effect.

The method shown in Figure 8 is adopted where the earth requires to be supported at shorter intervals than six feet, and consists of upright poling boards and struts as before, but with the addition of a horizontal timber termed a waling piece. The process of fixing is as follows:—The cutting is made, commencing at one end, and as soon as sufficient earth has been excavated a pair of poling boards and struts is inserted as in the first method; this process is repeated, fresh poling boards being fixed at distances apart varying with the nature of the earth, these distances being in some instances very short.

Horizontal members, 4 in. × 4 in. or upwards, are placed one on each side of cutting and strutted tightly against the poling boards. After about 12 feet has been thus cleared, the struts which were fixed first are then knocked out; a fresh depth is commenced, and treated in a similar way.

The third method is employed where the earth is very soft, and consists in laying horizontally boards usually 9 in. × 1½ in. against the sides of the excavation; the boarding laid in this manner is termed sheeting, which is supported by upright poling boards and struts, as shown in Figure 9. The method of fixing is as follows:—The earth is taken out to a depth of 9 inches, and a pair of boards is inserted and strutted apart; another depth of 9 inches is then taken out, and sheeting fixed as before. This process is repeated until a sufficient number of boards has been inserted, usually four; upright poling boards are then placed in position against the sheeting and strutted apart,

as shown in Figures 9 and 10, the first fixed struts are now struck and cleared away.

The above system may be improved upon, when the depth of the cutting is not too great, by cutting the sides

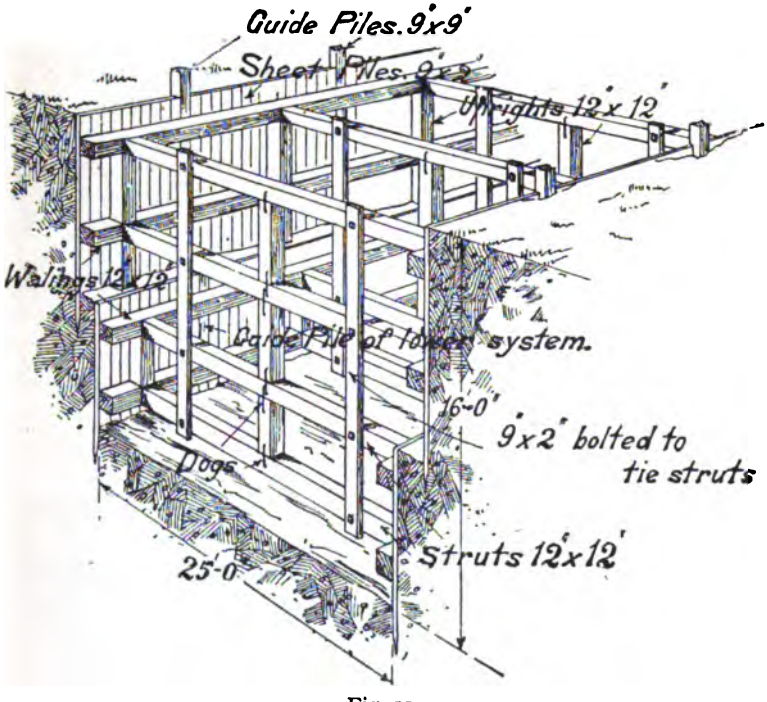


Fig. 11.

of the excavation to a slight batter, as shown in Figure 10; by so doing, the timbers are prevented from falling should the earth contract on becoming drained; it also facilitates the fixing of the struts.

Large Cuttings.—Continuous trenches, if made in bad ground, are generally arranged as shown in Figure 11.

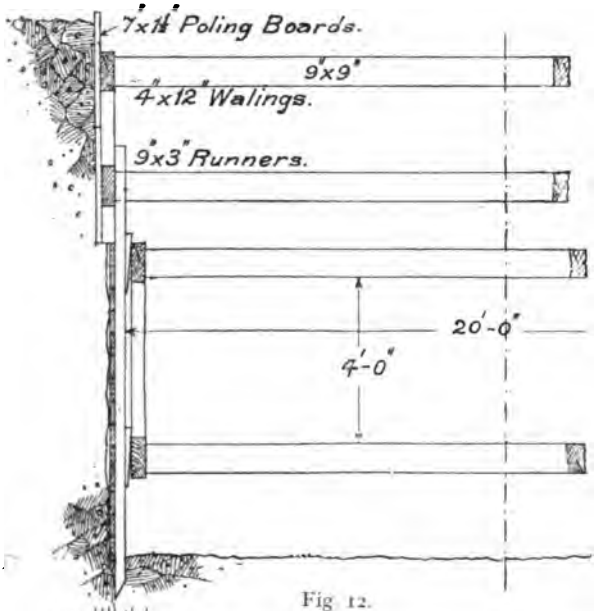

7"x14" Poling Boards.
9"x9"
4"x12" Walings.
9"x3" Runners.
20'-0"
4'-0"

Fig. 12.

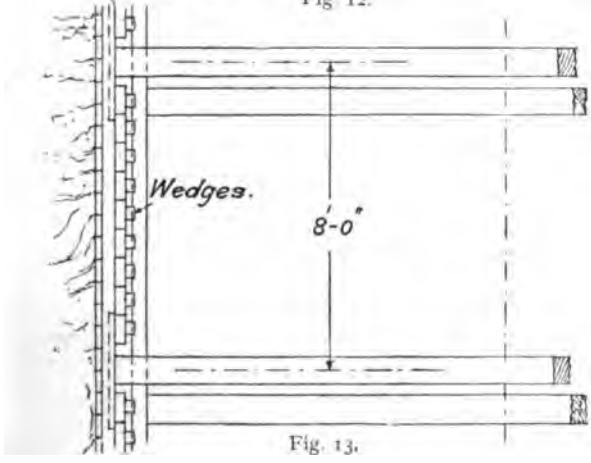

Wedges.
8'-0"

Fig. 13.

At intervals guide piles are driven in, to which walings are bolted, and sheeting consisting of boards about 10 feet long, shod with iron, termed runners, inserted between; these are driven a short distance into the ground, the earth between the two systems of piles being then taken out, and care taken not to excavate within a foot of the bottom end of the runners, which are again driven in and the process repeated. After the excavation of the first part, wales, consisting of whole timbers, are placed in position and strutted apart, the struts being also of balk timber. Long struts are supported in the direction of their length by short uprights secured to them by dogs. Uprights are also placed between the waling pieces as each fresh one is inserted.

After the ground has been excavated to the depth of the runners, a fresh system of piles and runners is driven slightly in advance of the former system, and the ground excavated as before. Cuttings are made in firm ground by excavating the earth and using ordinary sheeting, but if the cuttings are required to exceed 30 feet in width, it is found to be more economical to adopt a system of raking shores.

The method illustrated in Figures 12 to 14 is employed where the ground is soft and waterlogged, and is especially suitable for running sand. By this method as much of the earth is taken out as is possible without the sides of the excavation falling in, generally from 4 to 6 feet; this is then supported by upright sheeting, waled and strutted. The excavation is continued by lining the cutting with a secondary system of runners, *i.e.*, battens 7 in. × 2 in., pointed at lower ends and of about 9 feet in length. These are waled and strutted. Between each runner and waling piece a wedge is inserted. The method of proceeding with the excavation is as follows: the wedges securing one runner are loosened, the earth from the foot removed to a

depth of about 12 inches, the runner being dropped as the ground is removed and re-wedged. Each runner is successfully treated in this manner till the whole system has been lowered the necessary amount. It is essential that the feet of these runners should be at all times kept in the ground, as, if any portion of the vertical side of the excavation be

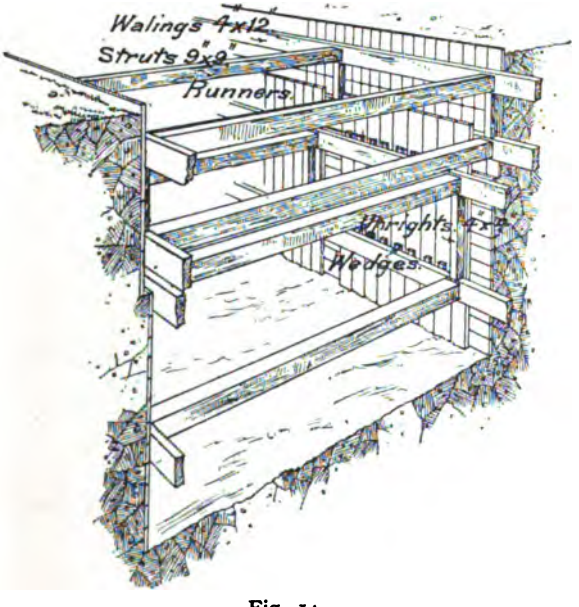


Fig. 14.

exposed, the earth is liable to ooze out and leave the back of the runners unsupported and cause the whole system to collapse.

Sinking Shafts.—It is often necessary to sink shafts for foundations, etc. These are made from 4 feet square and upwards, the former being the smallest size a man can work in without difficulty.

Shafts from 4 to 9 feet square are timbered as shown in Figure 15.

In ordinary soils the earth is excavated to a depth of at least 3 feet, and in firm soils 6 feet. The sides of the excavation are then lined with vertical sheeting, consisting of boards 9 inches wide, 1 inch to $1\frac{1}{2}$ inches thick, strutted apart by frames of horizontal waling timbers, a pair of which is placed in position against two opposite sides, and strutted apart by another pair driven tightly between and against the remaining sides, these being secured by cleats nailed to the fixed waling pieces. Another depth of earth is then taken out, and a second system of sheeting placed in, the upper ends of which lap about 1 foot over the lower ends of the first system of sheeting; another frame is placed in position as before, securing both systems of sheeting. Uprights are fixed in the angles between the waling pieces, and often at intermediate positions along their length. This process is repeated till the required depth is obtained.

Fig. 15.

The timbering requires to be supported if the depth be great, to prevent it from sliding down on the removal of the earth from its lower end. Where this has to be done, the upper end of the shaft is left projecting about 3 feet above the ground level. The two first fixed waling timbers at the ground level are continued through the shaft, and project several feet on either side, a good bearing on the solid ground on both sides of the shaft being thus obtained, as shown in Figure 16.

These members are usually out of balk timbers; they are strutted apart as described. An upright vertical timber is notched over this, and spiked to the face of

the waling timbers below, the whole being thus tied together.

These are often supplemented by similar timbers at the bottom of the shaft. These timbers are fixed in two pieces,

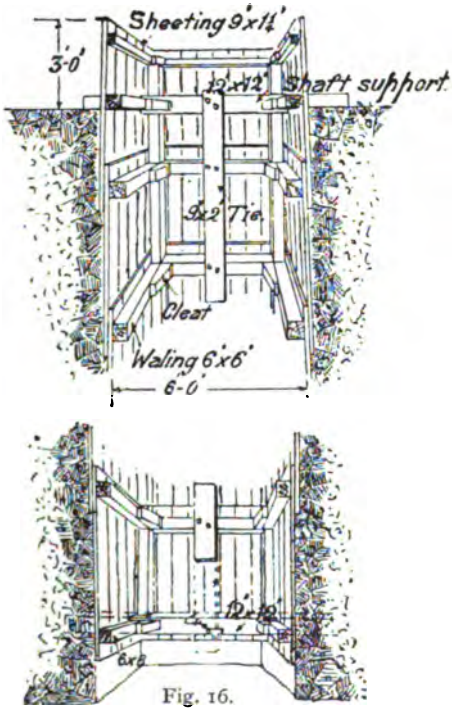


Fig. 16.

with a scarf in the centre; they project about 3 feet into both sides of the pit. A chain is sometimes emloyed in addition to the timber spiked to the walings.

Intermediate struts are required to support the horizontal walings where the size of the pit is above 9 feet square. One system of struts is fixed between two opposite sides,

being supported at their ends by cleats, as shown in Figures 17 to 19, these being necessary to prevent the timbers falling should they become loose during the pro-

Fig. 17.

gress of the works. The struts that support the remaining sides intersect by butting, as shown in Figure 18, against the first system, and are therefore fixed in two pieces. The struts at their intersection are supported by uprights, on

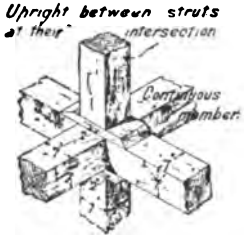


Fig. 18.

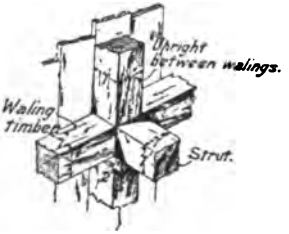


Fig. 19.

the upper ends of which short ends of timber are placed, projecting beyond the sides, acting as corbels, and forming a ledge upon which the shorter struts take a bearing.

The earth is raised from the bottom of the shaft, if of a great depth, by means of hoisting tackle ; but if the cutting

be shallow, stages are often erected in 6 feet heights, the earth being shovelled from one to the other till the top is reached.

Tunnelling.—In building operations it is often necessary

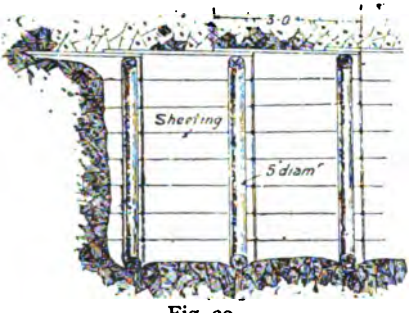


Fig. 20.

to bore a tunnel in order to construct drains, etc., the process being carried out as follows:—

Tunnels are made just large enough for a man to work

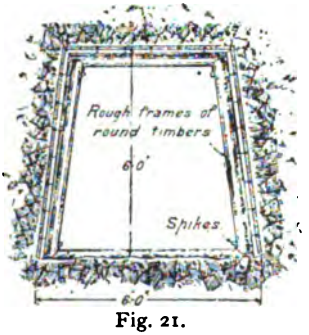


Fig. 21.

in, that is from 4 to 7 feet square. The earth is taken out in sections of about 3 feet at a time, poling boards of the same length being then placed against the upper surface, and kept in their position by a system of strutting,

consisting of a head, sill, and two uprights, out of either round or square timbers. The sill is placed in position first, being partly bedded in ground to prevent lateral motion, and being bedded in its correct vertical position by boning through from the sills previously bedded ; the head next, then the struts, which are cut and driven tightly between the two. The next section is then cleared out, commencing at the top, just enough being taken out there to allow of the next system of poling boards being inserted, these being arranged to overlap the first system at their back end, the two being then strutted up together; this process is repeated till the tunnel is finished.

If the soil be bad and the sides liable to fall in, they must also be lined by poling boards, these being kept in their place by the uprights.

Large spikes, similar in shape to floor brads, are driven into the head and sill, with their heads left projecting so as to be easily withdrawn, to secure the struts when in position. Wood cleats are often used in place of these.

These tunnels are usually made slightly tapering from the base to the head, as shown in Figures 20 and 21.

Foundations.—The construction of foundations varies with the nature and bearing strength of the soil. The following are the ordinary soils met with in practice and the method of treating them:—Rock, chalk, gravel, clay, and sand.

Rock.—Foundations laid upon the solid rock are undoubtedly secure, as far as settlement is concerned, such a substratum being practically incompressible. Rocks often have fissures and defective parts, and all gaps must be filled up with concrete, any unsound parts being cut away. Rock foundations are very expensive in working, owing to the extra labour involved in cutting them ; but where they occur they may be built upon direct.

Chalk.—Chalk varies considerably in hardness, being in

a dry or well-drained position very hard; but if subject to much wet it becomes saturated and thus rendered soft.

The sites for buildings on chalk soils should be drained, and precautions taken to prevent them becoming wet. Where this can be done, the structure can be built upon the chalk direct, after it has been levelled; but where heavy buildings are erected, or great weights concentrated, concrete should be employed to distribute the pressure.

Gravel.—Where lateral movement is not likely to occur, gravel is one of the best soils to build upon; it is not affected by the action of the atmosphere, and is practically incompressible.

Clay.—Clay is a good soil to build upon where the foundations are taken deep enough to be beyond the action of the atmosphere. Clay is very subject to expansion and contraction with the variations in temperature, and is therefore dangerous to build upon unless protected.

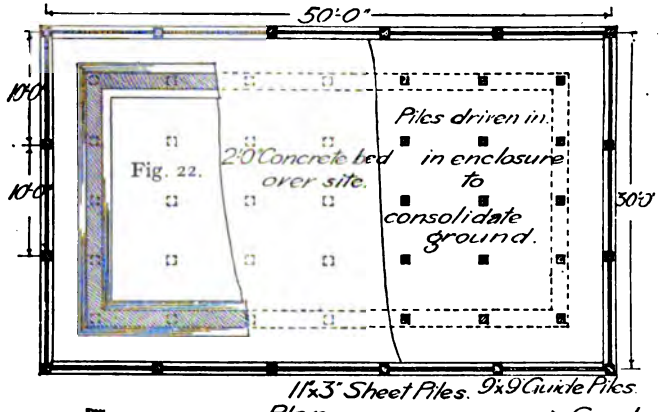
Sand.—Sand is a good material to build upon, if it can be kept dry and confined laterally; if subjected to the effects of running water it is liable to be scoured from about the foundation.

In all the above soils, with the exception of the rock, and the chalk when in a good condition, it is usual to form a bed of concrete, the area of which is proportioned to the weight to be carried and the bearing strength of the soil.

The following are cases that require special treatment:—(1) Soft soils of a great depth; (2) soft soils with hard strata beneath; (3) soils not having a uniform resistance, formed of rocks which have hollows or fissures filled up with some softer material.

1. Foundations in the first case may be made in one of two ways, or by a combination of both—(1) by sheet piling; (2) by forming the foundation on planks.

(1) *Sheet Piling.*—Sheet piling, as shown in Figures 22 and 23, is used to prevent the lateral escape of the soft soil;


50'0"
10'0"
10'0"
30'0"
Fig. 22.
2'0" Concrete bed over site.
Piles driven in in enclosure to consolidate ground.
11"x3" Sheet Piles.
9"x9" Guide Piles.
Plan

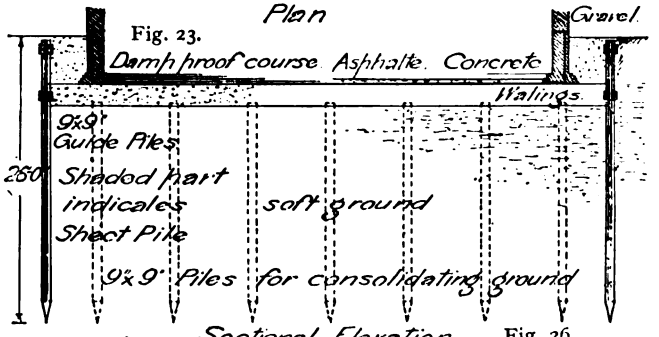


Fig. 23.
Gravel.
Damp proof course. Asphalte. Concrete
Walings.
9"x9" Guide Piles.
26'0"
Shaded part indicates Sheet Pile
soft ground
9"x9" Piles for consolidating ground
Sectional Elevation

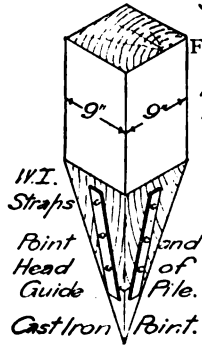
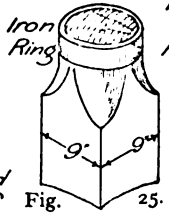


Fig. 24.
9"
9"
W.I. Straps
Point
Head
Guide
and of Pile.
Cast Iron Point.


Iron Ring
9"
9"
Fig. 25.

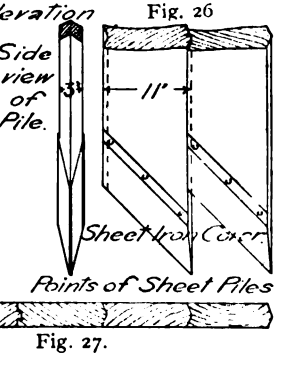


Fig. 26
Side view of Pile.
3"
11"
Sheet Iron Cover.
Points of Sheet Piles

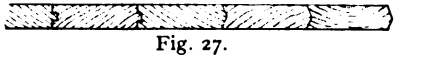


Fig. 27.

it consists of flat timbers, about 9 in. to 11 in. × 3 in., driven in and enclosing the site to be built upon, the area of the latter being sufficient to withstand the pressure brought to bear upon it; as the soil cannot escape, it must necessarily remain and support the structure. If the site is to be drained it must be done before the building is erected.

In order to enclose a site with sheet piling, it is necessary to drive guide piles into the soil, at intervals of from 6 feet to 10 feet apart. These usually consist of timbers 9 inches square and upwards, pointed and shod with iron at the lower extremities, as shown in Figure 24. The point consists of a pyramidal block of cast iron, about 6 inches in length, and having a base about 4 inches to 5 inches square; this has four mortices, about 2 in. × $\frac{1}{2}$ in. by about $\frac{3}{4}$ inch in depth. This is placed on the end of the pile, which has been cut as a truncated pyramid, the iron block completing the latter, and is fixed with four straps of wrought iron about 1 foot 6 inches in length, with the ends turned to fit in the mortices of the cast-iron points. The straps are fixed to the wood pile with large clout nails, the point being thus fixed, as shown in Figure 24. The guide piles are driven in to within about 2 feet of the ground; they are connected together by horizontal timbers about 9 in. × 6 in., bolted to them in pairs, with a space between equal to the thickness of the sheet piles. Two pairs of waling pieces are thus fixed, one at the ground level, and the other near the top of the piles in the spaces; between these the sheet piles are driven, the walings serving to keep them in an upright position. The joints of the sheet piles are prepared in three general ways: square, grooved and tongued, or bird's-mouthed together, the first and last being those most commonly used, the second and third being shown in Figure 27. The sheeting piles are pointed at their lower ends, in the way shown in Figure 26, to cause them to draw in one

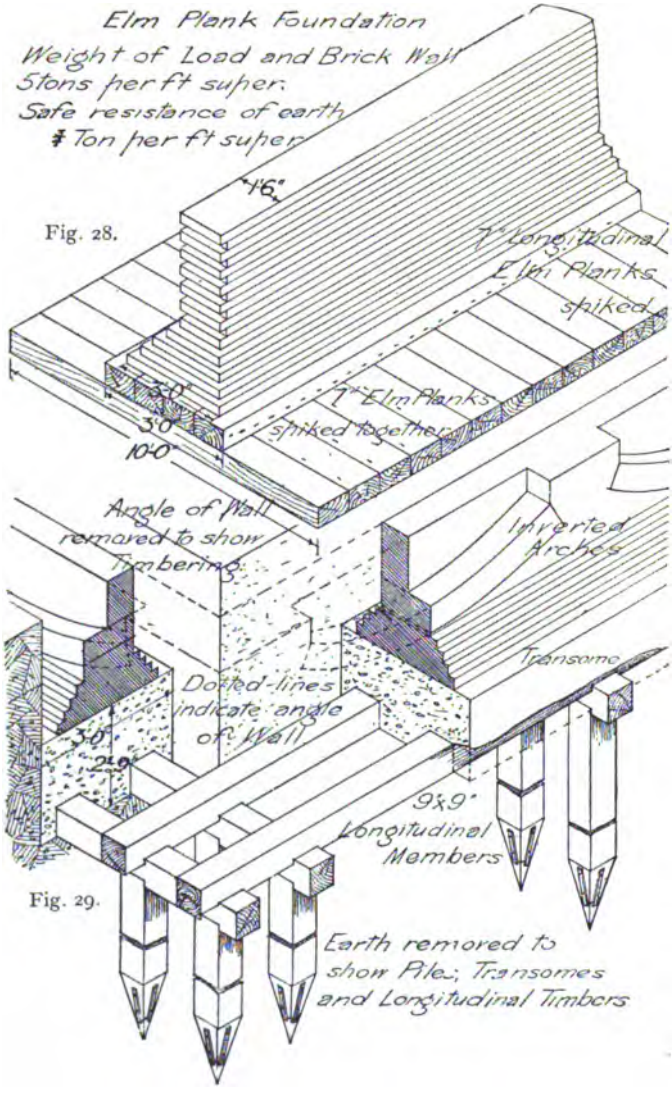

Elm Plank Foundation
Weight of Load and Brick Wall
5 tons per ft super.
Safe resistance of earth
½ Ton per ft super
1'6"
7" Longitudinal
Elm Planks
spiked
7" Elm Planks
spiked together
3'0"
3'0"
10'0"
Angle of Wall
removed to show
Timbering.
Inverted
Arches
Transoms
Dotted-lines
indicate angle
of Wall
3'0"
2'0"
9"x9"
Longitudinal
Members
Earth removed to
show Piles; Transomes
and Longitudinal Timbers

Fig. 28.

Fig. 29.

direction; they have a piece of sheet iron nailed over the end to protect the point.

The ground within the enclosure is frequently consolidated by driving in piles as shown in Figures 22 and 23, the tops of these being covered by a layer of concrete covering the whole site within the enclosed area.

(2) *Plank Foundations.*—These are useful in soft and very wet soils. Each may consist of a platform of timber formed by two layers of planking, as shown in Figure 28, the lowermost layer being placed at right angles to the length of the wall; the uppermost parallel to the length of the wall and being spiked to the first, on this the brickwork or masonry footings are commenced. The best and most plentiful wood in England for this purpose is elm, which if kept constantly wet is practically imperishable, but where exposed to alternations of wetness and dryness will rapidly decay. Timbers for this purpose should be treated to one of the preservative processes mentioned in the article on Timber in "Advanced Building Construction," notably creosoting.

EXAMPLE: Let it be required to support a wall 2 bricks in thickness and stressed with a load of 5 tons per superficial foot by a plank foundation, the safe resistance of the soil being $\frac{3}{4}$ ton per superficial foot. Determine width of foundation and thickness of planking required. Taking a length of 1 foot—

$$\therefore \text{ width of foundation} = \frac{\text{total load}}{\text{safe resistance of earth}}$$

$$\text{,, ,,} = \frac{5 \times 1\frac{1}{2}}{\frac{3}{4}}$$

$$\text{,, ,,} = 10 \text{ feet.}$$

The length of the transverse planks forming the foundation are first laid; then longitudinal planks, in this case say to a width of 3 feet 9 inches, are laid on and securely spiked to the transverse. Upon this the footings, commencing with a width of 3 feet, are bedded. Treating the

projecting planking as cantilevers, the lengths of which may be taken as 44 inches, the thickness may be determined as follows. The coefficient of rupture for elm C = 63 cwts.

$$M\,L = M\,R$$

$$\frac{w\,l^2}{2} = \frac{C \times b \times d^2}{6}$$

$$w = \frac{\frac{3}{4}}{12} \text{ tons per inch} = \frac{3}{48} \text{ tons per inch} = \frac{15}{12} \text{ cwts. per inch.}$$

then $$\frac{15 \times 44^2}{12 \times 2} = \frac{63 \times 12 \times d^2}{6}$$

and for safety let a factor of $\frac{1}{5}$ be taken,

then $$d = \sqrt{\frac{3025}{63}}$$

$$d = 7 \text{ inches nearly,}$$

as shown in Figure 28.

2. *Soft Soils with Hard Strata beneath.*—Cases of this description are commonly met with where buildings are

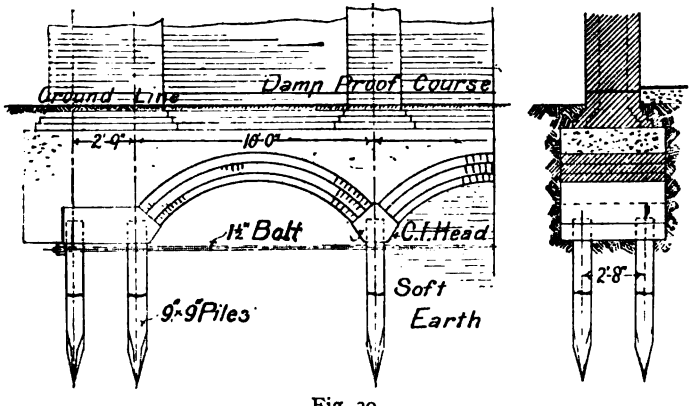


Fig. 30.

erected on the banks of rivers; they are usually dealt with in one of two ways—(1) by piling, until the pile refuses to be driven $\frac{1}{4}$ of an inch at each blow. Figure 30 illustrates piles driven in soft ground, supporting cast-iron heads,

brick relieving arches upholding concrete beam, forming the foundation. (2) By sinking piers down to the firm stratum.

(1) *Piling.*—The foundations are formed by driving piles

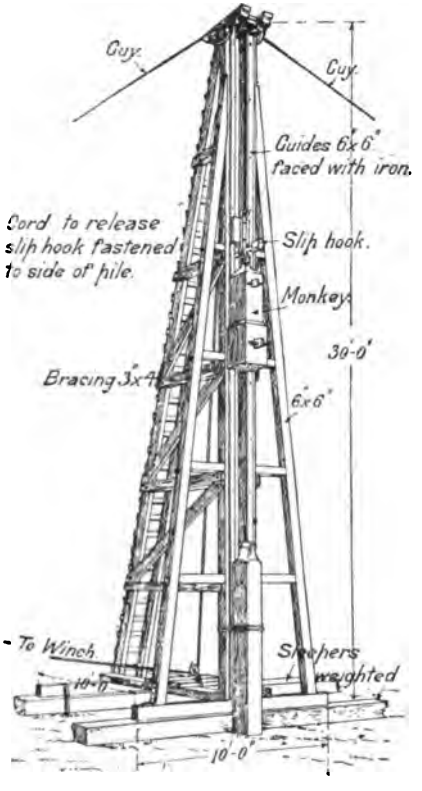


Fig. 31.

from 9 inches square and upwards, similar to the guide piles mentioned, till their points rest on the solid ground. These are driven in in varying distances apart under all the piers of the building, which should be connected by

inverted arches, as shown in Figure 29, to distribute the pressure uniformly along the foundation, and the piles being bridged both transversely and longitudinally by horizontal timbers of about the same sectional area as the piles, the whole being arranged as shown in Figure 29, which also illustrates the arrangement of the piles at the angle of a building. On the top of the timbering may be placed a platform of timber or a layer of concrete, on which the walls are built.

Pile Driving.—Piles are driven in the ground usually by means of a ram, which is a block of iron, sometimes called a monkey, weighing from 2 to 7 cwts, raised by a crab winch, actuated by manual or steam power. Figure 31 is an illustration of a pile engine, capable of being worked by manual or by steam power. The monkey in these machines is raised to a given height, when, by an arrangement known as a slip-hook, it is released, and descends with a force increasing directly as the height to which it had been raised. This distance ranges from 5 to 10 feet, usually 5 feet, as a comparatively heavy monkey with a shorter fall is found practically to be better than a light monkey with a great fall, the latter having the tendency to shiver the pile instead of forcing it downwards. Piles are considered to be sufficiently driven when the last blow does not sink the head more than $\frac{1}{4}$ inch.

The supporting power of a pile depends—(*a*) upon the resistance at the point to resist penetration; (*b*) the friction of the earth upon the sides of the pile; and (*c*), if projecting above the ground, its strength as a pillar.

The following empirical and well-known formula of Major Saunders, U.S. Eng., will give the safe load supported by piles in cwts.:—

Let d = the distance driven by last blow in inches
h = height fallen by monkey in inches
W = weight of monkey in cwts.

then safe loads in cwts. $= \frac{Wh}{8d}$

EXAMPLE: Determine the supporting power of a pile, which at the last blow of a weight of 10 cwts. falling freely through the height of 10 feet is urged through the ground a distance of $\frac{1}{4}$ of an inch.

Then by the formula

$$S\,L = \frac{Wh}{8d}$$

$$S\,L = \frac{10 \times 120}{8 \times \frac{1}{4}}$$

$$S\,L = 600 \text{ cwts.}$$

that is, 30 tons can be safely carried by every such pile. It can be shown by the laws of falling bodies as given in the accepted works upon Mechanics that the factor of safety taken by Major Saunders is $\frac{1}{8}$th of the ultimate resistance, for

$$\text{Force or resistance} = \text{mass} \times \text{acceleration}$$

$$\therefore R = ma$$

$$\text{but acceleration} = \text{velocity}^2 \div 2 \text{ space}$$

$$\therefore R = \frac{M\,v^2}{2\,S}$$

but S is in this case the distance passed through by a body when arrested at its greatest velocity till it comes to rest,

$$\text{but mass} = \text{weight} \div \text{gravity}$$

$$\therefore R = \frac{W\,v^2}{2g\,S}$$

but $v^2 = 2g\,S$ and S here equals h or height passed through by a falling body from its state of rest, till the instant it strikes the pile

$$\therefore R = \frac{W\,2gh}{2g\,S}$$

$$\text{that is } R = \frac{Wh}{S}$$

but S in this case is the d of Major Saunders' formula, being the distance that the pile is urged by last blow

$$\therefore R = \frac{Wh}{d}$$

Q.E.D.

Small steam hammers are sometimes used as pile-driving machines.

Rankine says that it appears from practical examples that the limits of the safe loads on piles are as follows:—

1. In piles driven till they reach the firm ground, 1,000 lbs. per square inch of area of head.

2. In piles standing in soft ground, by friction, 200 lbs. per square inch of area of head.

(2) *Sinking Piers.*—Piers of concrete or brick may be taken at intervals through the soft soil down to the hard substratum; these are connected by arches or girders, upon which the superstructure is raised. If the soil is sufficiently firm, timbered excavations are made, as shown in Figures 15 and 16, and concrete or brick piers may be formed; but if the soil is waterlogged, or in any way insecure, brick cylinders may be sunk or iron cylinders or caissons, as will be described later, these two cylinders being filled up with concrete and forming solid piers.

Concrete Piers.—The following example will illustrate concrete piers. Let a bed of soft soil 30 feet in depth overlie a compact gravel substratum, with a safe resistance of 8 tons per superficial foot. It is required to erect a wall with a load of 8 tons per lineal foot. Let the distance between the centres of adjacent piers be 15 feet, then the total load supported by each pier equals $15 \times 8 = 120$ tons. Let the weight of concrete pier be taken as 40 tons, then the total load on bearing stratum equals $120 + 40 = 160$ tons. The sectional area of concrete pier at base equals $160 \div 8 = 20$ superficial feet. Let the horizontal dimensions of pier to suit brickwork be taken as 5 ft. 6 in. $\times$ 4 ft., a timbered excavation having these internal dimensions is prepared, and then filled solid with concrete, the timbering being removed as the concrete is deposited, or, if the ground is uncertain, the timbering is frequently left in. Figures 32 and 33 show the above case.

Fig. 32.

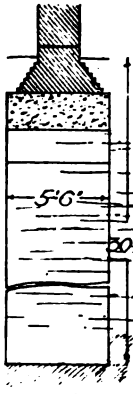
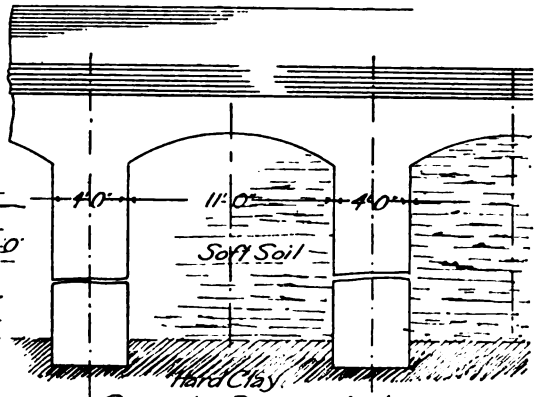
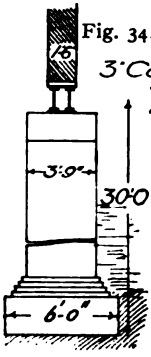


Fig. 33.



Concrete Piers and Arches

Fig. 34.



3' Cover Stone

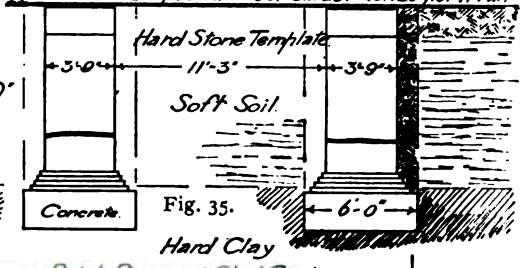


Fig. 35.

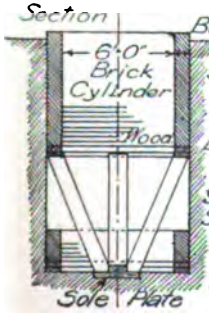


Fig. 36.

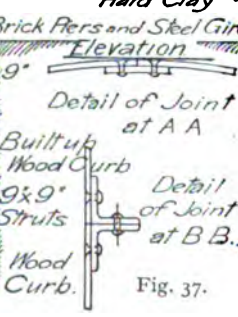


Fig. 37.

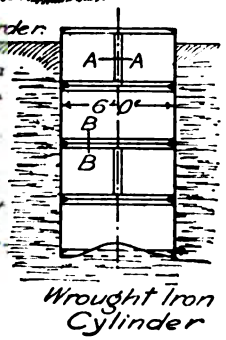


Fig. 38.

Brick Piers and Steel Girders.—Let a wall stressed with a load of 8 tons per lineal foot be carried by steel girders supported on brick piers in cement, the centre lines of which are 15 feet apart. Let the safe resistance of brickwork in cement be taken as 10 tons per superficial foot, cement concrete, 1 of Portland cement to 6 parts of ballast as 15 tons per superficial foot, and hard clay as 4 tons per superficial foot.

The area of pier = total load on pier ÷ safe resistance of brickwork, then—

$$\text{Area of pier at top course} = \frac{15 \times 8}{10} = 12 \text{ sup. ft.}$$

Let weight of pier be taken as 20 tons—

$$\text{Area of pier at bottom course} = \frac{\text{total load on footings}}{\text{safe resistance of footings.}} = \frac{120 + 20}{10} = 14 \text{ sup. ft.}$$

The resistance of this cement concrete being greater than the brickwork, it is unnecessary to calculate the footings. Let the weight of the concrete be taken as 5 tons—

$$\text{Area of concrete} = \frac{\text{total load on earth}}{\text{self resistance of earth}} = \frac{140 + 5}{4} = 36{\cdot}25 \text{ feet.}$$

Let the dimensions of the horizontal section of the concrete be taken as 6 feet by 6 feet, and that of the brick pier as 3 ft. 9 in. × 3 ft. 9 in.

The clear span between piers will now equal 11 feet 3 inches, and the total distributed load will equal 90 tons; then from a manufacturer's list a 16 in. × 18 in. compound steel girder 191 lbs. per foot run will carry safely a distributed load of 96 tons over an 11 feet 3 inch span. Figures 34 and 35 illustrate this example.

Sinking Shafts.—Brick shafts are sunk in one of two ways—First, by the method known as underpinning. In this a

circular hole is dug in the ground as deep as possible without causing the earth to fall, a circular built-up wood curb is then laid perfectly level at the bottom of the hole, on which the brickwork is raised to the top of the shaft, care being taken to pack the earth tightly behind the brickwork. When this part is completed, a hole is dug in the centre of the shaft as deep as possible, usually from 6 to 8 feet, a wood sole plate is bedded, inclined struts are then inserted, with one end resting on the plate, the other supporting the curb. At the completion of the fixing of these the earth is taken from beneath the curb at all parts to the level of the sole plate. A new curb is now inserted, and the brickwork built up to the underside of the old curb, and the struts removed. This process is repeated till the required depth is obtained, as shown in Figure 36.

Second method: A wood curb similar to the one in the last method, or an iron curb with a sharp edge, is employed here. The curb is laid on the ground, and the brick or stonework raised upon it. The earth inside the curb is removed, and on being taken from beneath, the curb with the brickwork sinks, fresh courses of the latter being added as the sinking proceeds. It sometimes happens that the friction on the sides of the brick lining is so great as to prevent the same from sinking; where this occurs, a second curb is placed inside the first, and a smaller shaft proceeded with in a manner similar to the first.

Iron Cylinder or Caisson.—This is sunk similarly to the brick shaft just described, fresh plates being added as the earth is removed. These being in one mass, as shown in Figures 37 and 38, there is less likelihood of their going out of the vertical; there is not so much friction on their sides, they therefore sink easier than the above, and are better where there is much water in the soil.

If the above-mentioned shafts have been sunk to the firm strata, they are usually filled with concrete, thus forming a

number of solid pillars. These are connected by arches or girders, and upon these the superstructure is raised.

Where soft places such as underground brooks traverse the tracks of walls it is usual to lay the concrete and bed the footings in the usual manner, and subsequently to build a rough relieving arch through the thickness of the wall over the soft parts as shown in Figures 39 and 40.

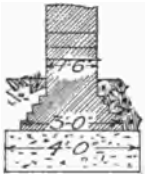
3. *Soils not having a Uniform Resistance.*—Soils of this description, where the ground consists of rock or firm ground in some parts, and in others of a soft soil, require careful treatment to prevent unequal settlement. The best method under these conditions is to cover the whole site with a bed of concrete, this being further strengthened by embedding steel rails into the concrete, spanning the soft parts; in this way a solid, hard platform is obtained over the whole site.

Soft soils subjected to Unequal Pressures.—Where the pressures of a building are concentrated at piers placed at intervals in the lengths of the walls there is a danger of unequal settlements and fractures in the unloaded portions of the walls; to counteract this tendency inverted arches, as shown in Figures 41 and 42, are constructed between the piers, distributing the pressures uniformly over the whole lengths of the foundations.

Benching.—Where buildings are erected on the side of a hill, and it is not practicable nor economical to excavate the whole site of the building to one level, the ground should be benched—that is, cut into a number of horizontal steps; on these the foundations are laid and the walls raised. The wall, if of brick, should be carried up in cement to the highest level of the foundation, and in large blocks of stone, if in masonry, in order to reduce the inequality of settlement due to the varying number of bed joints.

Subsoil Drainage.—In low-lying districts, and in damp

Fig. 39.



Section.

Fig. 40.

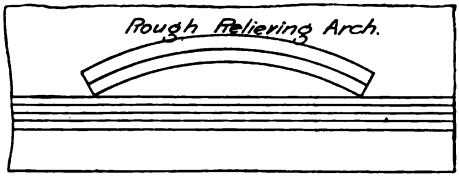
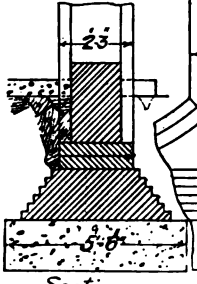
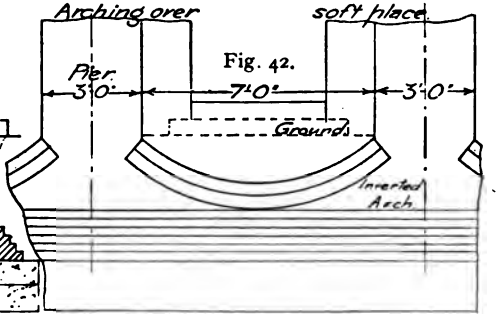


Fig. 41.



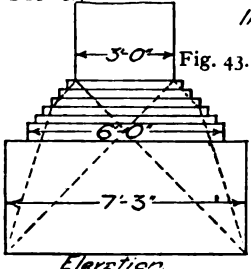
Section.

Fig. 42.



Inverted Arches.

Fig. 43.



Elevation.

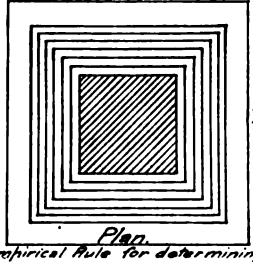
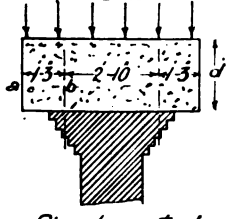


Fig. 44.

Plan.

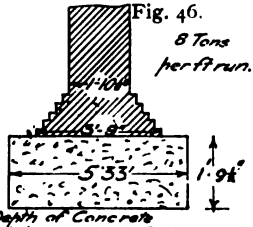
Empirical Rule for determining depth of Concrete.

Fig. 45.



Pier Inverted.

Fig. 46.



Depth of Concrete determined by Calculation.

soils generally, the site for any building should be drained thoroughly before the structure is commenced, especially if there is the remotest possibility of any future cuttings being made, such as would be required for sewers or railways, which, by acting as a drainage system, would cause the failure of the foundations. Dampness in the soil has a deleterious effect upon the health of the inmates, and also causes defects in the building: first, by the expansion and contraction of the earth, consequent upon the absorption and evaporation of moisture, which tends to rend the walls; secondly the damp is drawn up the walls. This may be stopped by an efficient damp-proof course; but where a wood floor is built on the ground floor, the timbers will be liable to dry rot. This may to a certain extent be avoided by ventilating the timbers; but even under these conditions the timbers invariably rot by being subjected to alternations of dampness and dryness. To reduce the possibility of this defect, a layer of concrete at least 6 inches thick should be spread over the whole area covered by the building, and a damp-proof course over the whole site, as shown in Figures 47 and 48.

Where isolated buildings have to be erected, the method of draining the land would be as follows:—A trench or ditch is dug about the whole site to intercept any water that may flow over the land, and prevent it passing over the site. The site is divided into a number of parallel bays by narrower trenches than the above, all having a fall towards the lowest part of the site. Between these a number of still smaller trenches are cut, being arranged to a herring-bone pattern. These diverge from the centre line of the bay in the direction of the fall, and discharge into the above-mentioned trenches; the latter empty themselves into the enclosing ditch, from which the water is conveyed by a continuation of the latter, or a pipe, to the nearest stream, if the land is nearly level; or if the ground is on the slope, the water is discharged over the same at a lower level.

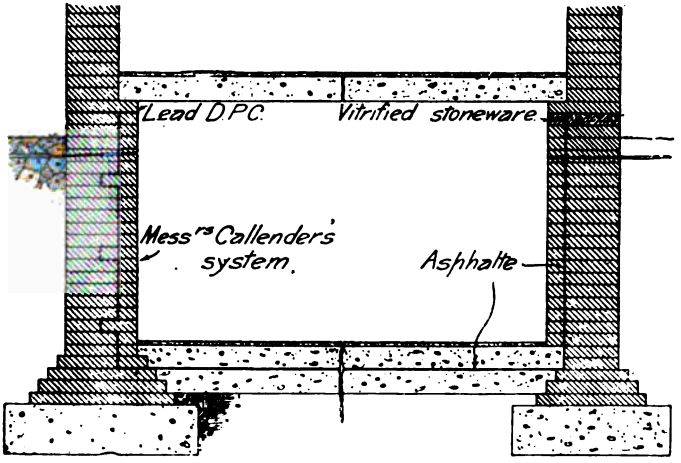

Lead D.P.C.
Vitrified stoneware
Messrs Callender's system.
Asphalte

Fig. 47.

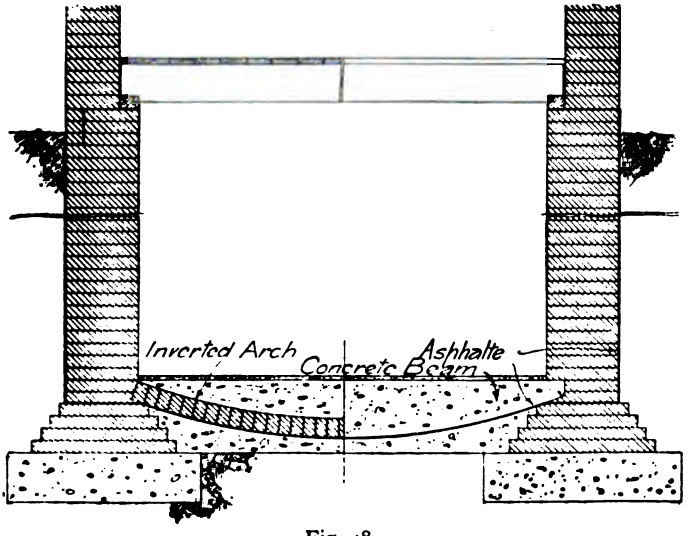

Inverted Arch
Concrete Beam
Asphalte

Fig. 48.

Trenches.—The depths of trenches usually vary from $2\frac{1}{2}$ to 6 feet; they are cut as narrow as possible. The bottoms of the trenches are cut to regular falls of not less than 1 in 100. The distance between the smallest trenches varies with the soil, being about 20 feet in clay to 40 feet in lighter soils.

A duct is formed at the bottom of the trenches for the conveyance of water. This may be done in one of three ways, as follows:—(1) by placing a layer of large stones at the bottom of the trenches, through the interstices of which the water can flow; (2) a channel is formed with

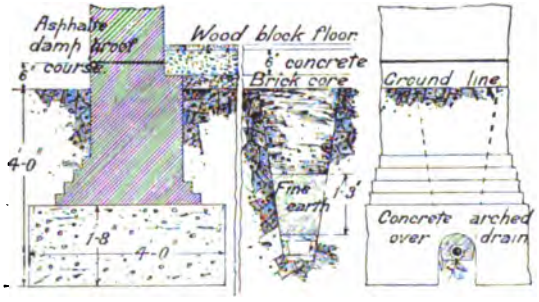


Fig. 49. Fig. 50.

tiles, either flat or curved, or of thin slabs of stone (as shown in figure 49)—where a thinly stratified stone is abundant, a space is left between the joints of the pieces to allow the water to drain into the channel; (3) agricultural drain pipes, as shown in Figure 50, are used, being made of earthenware, about 15 inches in length and about 2 inches diameter in the smallest drains, and from 3 to 4 inches in the main drains. The pipes are laid dry, with a butt joint in the bottom of the trench; the ends are placed close together, the uneven surfaces leaving a sufficient space for the water to find its way through. Collars are sometimes placed over the joints to prevent dirt finding its way

in, and to prevent the ends of the pipes getting removed from each other while the trench is being filled. The collars consist of a piece of pipe of a larger diameter than the drain, into which the ends of the latter fit loosely.

Filling In.—The space above the stones, tiles, or pipes should be filled in with a fine porous earth to a depth of at least 15 inches, and above this the ordinary earth may be placed, the latter being shot in lightly at first, but finally well rammed.

Failure and Prevention.—Such a drainage system is liable to failure from the following causes :—(1) by the accumulation of silt and vermin in the pipes ; (2) roots of trees, which push the pipes out of their place and extend up the pipe, and finally stop them up ; (3) where the pipes are under a building they are liable to fail by the settlement of the latter.

(1) The first danger may be avoided by building a catchpit at intervals, which consists of a brick chamber, into which the pipe discharges ; all the matter in suspension falls to the bottom of the chamber, the fluid flows off through the continuation of the pipe on the opposite side of the catchpit. To prevent vermin, such as mice, etc., from getting up the pipes, all the outlets should be covered by a wire guard or broken glass.

(2) If laid near trees, collars should be employed, or socketed pipes set in cement.

(3) If occurring under the walls of a building, a space should be left and arched above them, in order that the pressure may not be brought to bear on the pipes on the settlement of the building and consequent compression of the earth.

In the model bye-laws issued by the Local Government Board, the following requirement is made :—" Every person who shall erect a new building shall cause the subsoil of the site of such building to be effectually drained by means of suitable earthenware field-pipes properly laid to a suitable outfall whenever the dampness of the site renders such

a precaution necessary. He shall not lay any such pipe in such a manner, or in such a position, as to communicate directly with any sewer or cesspool, or with any drain constructed or adapted to be used for conveying sewage, but shall provide a suitable trap with a ventilating opening at a point in the line of the subsoil drain as near as may be practicable to such trap."

Widths and Depths of Concrete Foundations.—For heavy buildings the widths of the concrete in the foundation should be determined by the bearing strength of the ground on which they rest. The following table is useful in calculating the widths :—

Table of Safe Loads in Tons, per superficial foot.	Tons.
Brickwork in mortar (sound stocks), grey chalk lime and sand, 1 to 2, six months old	2½
Lias lime and sand, 1 to 2, six months old	5
Brickwork in cement (hard stocks), Portland cement and sand, 1 to 1, three months old	10
(Ordinary well-burnt stocks) Portland cement and sand, 1 to 1, three months old	8
Concrete—Portland cement and river ballast, 1 to 6, twelve months old	15 to 20
Lias lime and river ballast, 1 to 6, twelve months old	2½ to 4½
Rubble masonry in lias lime	4

The following table of safe resistances of earths is given by Newman :—

Description of Earth.	Approximate Safe Maximum Load in Tons per Square Foot.
Bog, morass, quicksand, peat moss, marsh-land, silt ...	0 to 0·20
Slake and mud, hard peat turf	0 to 0·25
Soft, wet, pasty, or muddy clay, and marsh clay ...	0·25 to 0·33
Alluvial deposits of moderate depths in river beds, &c. *Note.*—When the river bed is rocky and the deposit firm, they may safely support 0·75 ton, but not more.	0·20 to 0·35

Description of Earth.	Approximate Safe Maximum Load in Tons per Square Foot.
Diluvial clay beds of rivers	0·35 to 1·00
Alluvial earth, loams and loamy soil (clay and 40 to 70 per cent. of sand), and clay loams (clay and about 30 per cent. of sand)	0·75 to 1·50
Damp clay	1·50 to 2·00
Loose sand in shifting river bed, the safe load increasing with depth	2·50 to 3·00
Upheaved and intermixed beds of different sound clays	3·00
Silty sand of uniform and firm character in a river bed, secure from scour, and at depths below 25 feet ...	3·50 to 4·00
Solid clay, mixed with very fine sand	4·00
Note.—Equal drainage and condition is especially necessary in the case of clays, as moisture may reduce them from their greatest to their least bearing capacity. When found equally and thoroughly mixed with sand and gravel their supporting power is usually increased.	
Sound yellow clay, containing only the normal quantity of water	4·00 to 6·00
Solid blue clay, marl and indurated marl, and firm boulder gravel and sand	5·00 to 8·00
Soft chalk, impure and argillaceous	1·00 to 1·50
Hard, white chalk	2·50 to 4·00
Ordinary superficial sand beds	2·50 to 4·00
Firm sand in estuaries, bays, &c.	4·50 to 5·00
Note.—The Dutch engineers consider the safe load upon firm clean sand as 5½ tons per square foot.	
Very firm, compact sand foundations at a considerable depth, not less than 20 feet, and compact sandy gravel	6·00 to 7·00
Note.—The sustaining power of sand increases as it approaches a homogeneous gravelly state.	
Firm shale, protected from the weather, and clean gravel	6·00 to 8·00
Compact gravel	7·00 to 9·00
Note.—The relative bearing powers of gravel may be thus described:—1. Compact gravel; 2. Clean gravel; 3. Sandy gravel; 4, Clayey or loamy gravel. Sound, clean, homogeneous Thames gravel has been weighted with 14 tons per square foot at a depth of only 5 feet below the surface, and presented no indication of failure. This gravel was similar to that of a clean, pebbly beach.	
Rocks for foundations and general work	8·00 to 18·00
Rocks, sandstones, that may be crumbled in the hand	1·50 to 1·75

There are two methods of approximately determining the bearing resistance of the soil. 1. By taking a square piece of wood of a given area, say, 1 foot, and loading it until the ground is impressed. 2. By taking a bar of iron of given sectional area and dropping the same from a given height and noting the depth to which the bar sinks into the ground before it comes to rest, and then deducing from the laws of falling bodies the resistance that has been offered.

EXAMPLE.—An iron bar 6 inches by 6 inches in section weighing 30 lbs. falls freely through a height of 10 feet and is found to sink into the ground $\frac{1}{2}$ an inch; then, by Major Saunders' formula—

$$R = \frac{W \times h}{d}$$

$$= \frac{30 \times 120}{\frac{1}{2}}$$

$$= 7{,}200 \text{ lbs. per 36 square inches.}$$

$\therefore$ for 1 square foot R = 28,800 lbs., and for safety let

$$\frac{28800}{8} = 3{,}600 \text{ lbs. per square foot.}$$

The maximum load in London is usually taken as $1\frac{1}{2}$ to 2 tons per superficial foot. Thus, if a brick wall built in lias lime mortar will safely carry 5 tons per superficial foot of section, and assuming the earth to be capable of supporting safely a uniform load of $1\frac{1}{2}$ tons per superficial foot, then the width of concrete should be $5 \div 1\frac{1}{2}$, or nearly 3·33 times the thickness of the wall. The depth or thickness of the concrete is usually determined by experience, but as the most dangerous fracture that is likely to occur in concrete foundations is at the angle of about 45° to the base, causing the foundations to rupture in a number of triangular prisms or pyramids shearing or sliding upon each other, it would be better determined by drawing lines as in Figures 43 and 44, inclined 45° to the plane of the bottom of the

wall above the footings from the thickness of the wall, and the depth required is shown by the intersection of these lines with the vertical lines, indicating the width of the concrete, supposing that the base of the foundations is on ground that is not likely to escape laterally under pressure.

The following illustrates the application of this theory to piers :—

EXAMPLE : Calculate the necessary dimensions of brick footings, and the width and depth of concrete for a square brick pier of 3 feet side, stressed to 5 tons per square foot of section, the safe loads of lias lime concrete, and earth being taken as 3 and 1 tons per superficial foot respectively.

The area of the base of the footings in feet will be the total load divided by the safe load per superficial foot of concrete. Let the weight of the brick footings be taken as approximately 1 ton, then—

$$\frac{\text{Total load}}{\text{Safe load upon concrete}} = \frac{45 + 1}{3} = 15\tfrac{1}{3} \text{ feet super.}$$

The side of base footings will therefore equal in nearest brick dimensions 4 feet $1\frac{1}{2}$ inches; but it is usual to make the side of lowest course of footings twice the width of the pier, that is, in this case, 6 feet.

The area of the base of the concrete in feet will be the total load divided by the safe load sustained per superficial foot by the earth. Let the weight of the concrete be taken as approximately 5 tons, then—

$$\frac{\text{Total load}}{\text{Safe load upon earth}} = \frac{45 + 1 + 5}{1} = 51 \text{ feet super.}$$

and the side of base of concrete will therefore equal 7·14 feet, say 7 feet 3 inches, as shown in Figures 43 and 44.

Figure 43 shows the footings and concrete to satisfy the preceding calculations and the Bye-laws, the brick footings

being splayed at the usual angle, and the depth of concrete being determined by drawing lines at 45° from base of wall and the point of intersection with the calculated width of concrete, will give the depth, as previously explained. Figure 43 shows how the brick footings are usually arranged in practice, which, in this case, may be supposed to be substituted for the equivalent depth of concrete.

Depth of Concrete by Calculation.—The depth of concrete may be obtained by calculating as for a cantilever under a distributed load, therefore the formula, as given in the chapter on girders in my "Advanced Building Book," is—

$$\mathrm{M\,L} = \mathrm{M\,R}$$
$$\frac{w\,l^2}{2} = \frac{\mathrm{C} \times b \times d^2}{6}$$
$$\therefore\ d^2 = \frac{6\,w\,l^2}{2\,\mathrm{C}\,b.}$$

EXAMPLE: In a wall of 1 foot $10\frac{1}{2}$ inches thick, there is a load of 8 tons upon every lineal foot. Determine the depth of cement concrete required. The value of C is given as 2·5 cwts., and the factor of safety is to be $\frac{1}{8}$ of the ultimate resistance.

Let the safe resistance of the earth be taken as $1\frac{1}{2}$ tons per superficial foot, then—

$$\text{The width of concrete} = \frac{\text{total load}}{\text{safe resistance of earth}}$$
$$= \frac{8}{1\frac{1}{2}} = 5{\cdot}33 \text{ feet.}$$

Figure 45 shows the wall inverted to realise more clearly the pressure. The part between *b* and *c* may be considered as under compressional stress only, whilst the distances *a b*, *c e*, represent the lengths of the cantilevers;

$$\frac{w\,l^2}{2} = \frac{\mathrm{C} \times b \times d^2}{6}$$

but for safety let a factor of $\frac{1}{8}$ be taken, then—

$$\frac{w\,l^2}{2} = \frac{C \times b \times d^2}{6 \times 8}$$

$$\therefore\ d^2 = \frac{6 \times 8 \times w\,l^2}{2 \times C \times b}$$

but distributed load in cwts. per inch of length of cantilever $= \frac{160}{64}$

$$\therefore\ d = \sqrt{\frac{6 \times 8 \times 160 \times 15 \times 15}{2 \times 2\frac{1}{2} \times 12 \times 64}}$$

$$= 21{\cdot}21 \text{ inches.}$$

Tall Piers.—The height of a pier in brickwork above any horizontal section should not exceed twelve times the least dimension of that section. The area of the base of such piers should be proportioned to the pressure they have to resist. For economy in labour the sides of the piers are usually carried up vertically and have the same sectional area at top as at the bottom, that is, they have an excess of strength and therefore of material. For perfect and economical construction the horizontal sections of a pier at any part should be proportioned to the pressure upon them. It would only be in the cases of very tall piers supporting very heavy loads that it would be economical to design the piers to the theoretical sections, but if the piers are sufficiently large to build hollow then the theoretical section may be kept and built to with economy.

EXAMPLE I.: Let it be required to support a load of 50 tons at a height of 30 feet on a brick pier approximately square, the safe load on the brickwork being taken as 6 tons per superficial foot, and the weight of brickwork 112 lbs. per cubic foot.

$$\text{The area of the top course} = \frac{\text{total load}}{\text{safe load}}$$

$$= \frac{50}{6} = 8\tfrac{1}{3} \text{ tons per sup. foot.}$$

Let A = area of required base
P = area of top base
r = ratio of increase of each block over the block above
R = $(1 + r)$
n = number of unit blocks counting from the top

then $A = P R^n$.

Consider blocks of $1' \times 1' \times 1'$ to weigh 112 lbs.

then area of the lower block required to support itself $\left\{ = \dfrac{\text{weight of brickwork}}{\text{safe load}} \right.$

$$= \frac{112}{6 \times 2240} = \frac{1}{120}$$

$$\therefore r = \frac{1}{120} \text{ and } R = \left(1 + \frac{1}{120}\right) = \frac{121}{120}$$

$$A = P R^n$$

$$= \frac{25}{3}\left(\frac{121}{120}\right)^{30}$$

$$= 10{\cdot}69 \text{ square feet.}$$

The top of pier has an area of $8{\cdot}\dot{3}$ superficial feet, and the base of lowest course 10·69 superficial feet, and the area of the base of any intermediate block would be calculated by the same formula.

If it be required to build the sides of this pier vertical an increase in the area of the base would be necessary to support the increased mass to maintain the maximum pressure of 6 tons per superficial foot. The increased area may be obtained in the following manner :—

Let x = side of required vertical faced pier
x^2 = area of required vertical faced pier
A = area of computed pier
w = weight of brickwork per cubic foot

then $(x^2 - A)$ safe load $= x^2 h w -$ weight of computed pier.

The content of computed pier may be obtained by the formula for the sum of a geometrical series, viz.—

$$\frac{P(r^n - 1)}{r - 1} = 282{\cdot}7 \text{ cubic feet}$$

and the weight $= 282{\cdot}7 \times w = 282{\cdot}7 \times 112 = 31662$

$$\therefore (x^2 - 10{\cdot}6)\,6 \times 2240 = x^2 \times 30 \times 112 - 31662$$
$$x^2\,(13340 - 3360) = 142464 - 31662$$
$$x^2 = \frac{110801}{9980}$$
$$= 11{\cdot}1 \text{ sup. feet sectional area of required pier.}$$

If a square pier, then $x = 3{\cdot}\dot{3}$ feet; the nearest brick dimension would be $4\frac{1}{2}$ bricks, that is 3 feet $4\frac{1}{2}$ inches.

EXAMPLE II.: Let it be required to support a load of 1,000 tons at a height of 100 feet on a brick pier, the safe load on the brickwork being taken as 6 tons per superficial foot, and to be stressed to this amount at any horizontal section, and the weight of the brickwork as 112 lbs. per foot cube.

The dimensions of the pier at top to be 27′ 0″ × 8′ 0″

$$\therefore P = \frac{\text{total load}}{\text{safe load}} = \frac{1000}{6} = 166{\cdot}\dot{6} \text{ sup. feet}$$

$$\text{at } 20' \text{ down } A = P\,R^{20}$$
$$= 166{\cdot}\dot{6} \times \left(\frac{121}{120}\right)^{20} = 196\ 68 \text{ sup. feet}$$
$$40' \text{ down } A = P\,R^{40}$$
$$= 166{\cdot}\dot{6}\left(\frac{121}{120}\right)^{40} = 232{\cdot}19 \text{ sup. feet}$$
$$60' \text{ down } A = P\,R^{60}$$
$$= 166{\cdot}\dot{6}\left(\frac{121}{120}\right)^{60} = 274{\cdot}11 \text{ sup. feet}$$
$$80' \text{ down } A = P\,R^{80}$$
$$= 166{\cdot}\dot{6}\left(\frac{121}{120}\right)^{80} = 323{\cdot}6 \text{ sup. feet}$$
$$100' \text{ down } A = P\,R^{100}$$
$$= 166{\cdot}\dot{6}\left(\frac{121}{120}\right)^{100} = 382{\cdot}03 \text{ sup. feet.}$$

To obtain the varying thicknesses of the pier at each 20 feet in its height. Let the batter be taken as 1 in 25, then commencing at the 100 feet level, then the dimensions as shown in Figures 52 and 53 at—

100 feet level	=	8·0′	×	27·0′
80 ,, ,,	=	9·6′	×	28·6′
60 ,, ,,	=	11·2′	×	30·2′
40 ,, ,,	=	12·8′	×	31·8′
20 ,, ,,	=	14·4′	×	33·4′
0 ,, ,,	=	16·0′	×	35·0′

The thickness at the 100 feet level has already been obtained and is 3 feet, then at the 80′ level, then the thickness x may be obtained as follows :—

$$(\text{round of walls} - 4x)\,x = \text{required area}$$
$$76{\cdot}4x - 4x^2 = 196{\cdot}68$$
$$x^2 - 19{\cdot}1x = -49{\cdot}17$$
$$x^2 - 19{\cdot}1x + (9{\cdot}55)^2 = 91{\cdot}212 - 49{\cdot}17$$
$$x - 9{\cdot}55 = 9{\cdot}55 - 6{\cdot}48$$
$$x = 3{\cdot}07$$

Then determining the thicknesses at the other levels in a similar manner the thicknesses required as shown in Figure 53 will be as follows :—

100 feet level	3·0′
80 ,, ,,	3·07′
60 ,, ,,	3·35′
40 ,, ,,	3·68′
20 ,, ,,	4·09′
0 ,, ,,	4·56′

The area of spread for the footings and concrete may be determined as has been previously explained, the weight of the pier above the footings may be ascertained by the formula for the summation of a geometrical progression. As the brickwork would for practical reasons be built in parallel thicknesses there would be a loss in working from the top downwards by this formula, and similarly there would be a gain in working from the bottom upwards, the actual quantity may be taken as the arithmetic mean of these two without any appreciable error. From the top downwards, let blocks 1 foot deep be taken.

$$S = \frac{A\,(r^n - 1)}{r - 1}$$
$$= \frac{166{\cdot}\dot{6}\left(\frac{121}{120}^{100} - 1\right)}{\frac{121}{120} - 1}$$
$$= 25641$$

Fig. 52. Fig. 53.

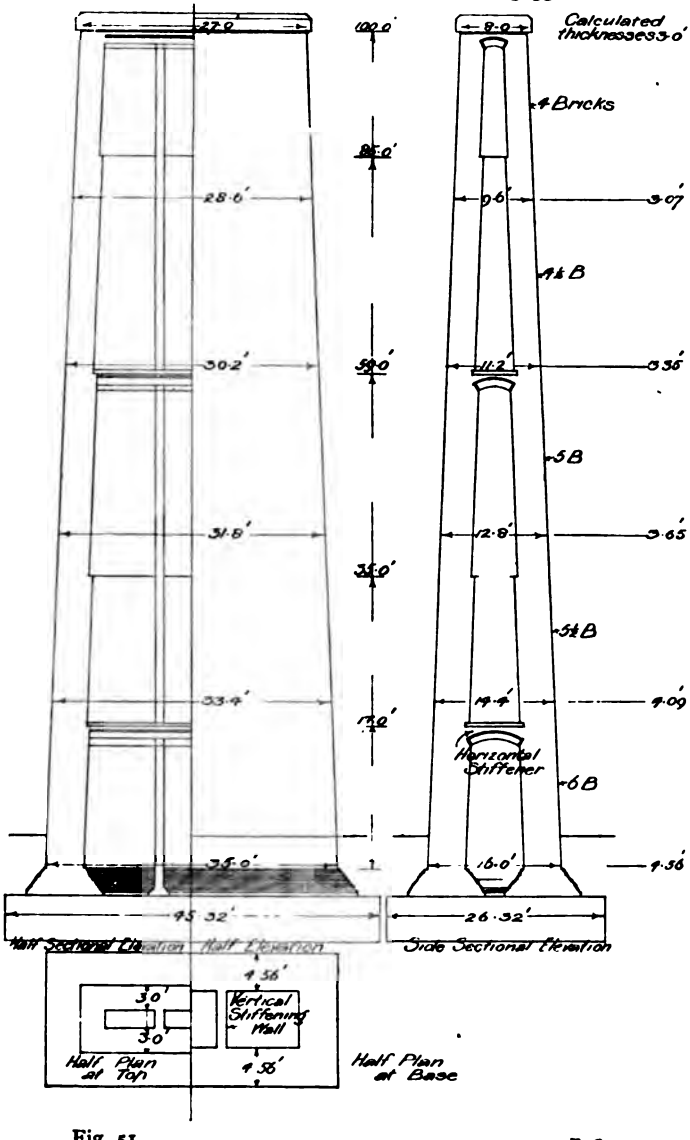


Fig. 51.

From the bottom upwards :

$$S = \frac{A(1 - r)}{1 - r}$$

$$= \frac{382{\cdot}03\left(1 - \frac{120^{100}}{121}\right)}{1 - \frac{120}{121}}$$

$$= 26081$$

therefore the mean of these two is 25,861 cubic feet, and the weight will be 1,284·05 tons.

Figures 51, 52, and 53 show the construction of the pier with the necessary stiffening walls and arches.

Steel and Concrete Foundations.—A common method of constructing foundations of walls and piers of buildings practised in America where the structure rests upon a yielding stratum, is to embed steel joists in concrete in order to extend the bearing surface. The methods of employing timber in foundations are defective unless it is known that the timber can be kept permanently wet or dry, as they quickly rot. Iron or steel rails embedded in concrete are not open to this objection, but where great weights are concentrated on points or lines, as under piers or walls, the rails are subject to deflection unless the concrete bed is very thick. I beams as now used are in every way superior to the above, as by employing a depth enough to reduce the deflection to a minimum, a comparatively thin bed of concrete only need be used, and a sufficient saving be effected in excavation and concrete to compensate for the employment of the steel beams.

This method of constructing foundations is especially suitable where the structure is erected upon a comparatively thin hard stratum overlying a soft and yielding stratum, and where consequently it would be unwise to damage the upper crust.

To prepare foundations in this manner it is usual to lay

a bed of concrete of from 4 to 12 inches in thickness, and on this to place the beams at right angles to the wall at centres varying from 9 inches to 24 inches, as shown in Figure 55.

EXAMPLE: A wall 1 foot $10\frac{1}{2}$ inches in thickness supports a load of 15 tons per lineal foot. The width of footings at base to comply with bye-laws is 3 feet 9 inches. The safe bearing strength of earth is $1\frac{1}{2}$ tons per superficial foot; therefore—

$$\text{the width of foundation} = \frac{\text{total load}}{\text{safe resistance of earth}}$$

$$= \frac{15}{1\frac{1}{2}} = 10 \text{ feet.}$$

Taking the distance of centre of projection of footings to edge of foundations on either side to equal 3 feet $7\frac{1}{8}$ inches, say 3 feet 7 inches, and the rolled steel joists to be placed at 2 feet centres, and from a manufacturer's list that a 5 in. × 12 in. joist with flanges ·56 inch thick and web ·35 inch, determine the stress per square inch in section.

From formula for cantilevers under distributed loads as given in my "Advanced Building Book"—

$$\frac{wl^2}{2} = \frac{S\,I}{\delta}$$

$$\text{but } W = wl$$

$$\therefore \frac{Wl}{2} = \frac{S\,I}{\delta}$$

$$\therefore S = \frac{\delta\,Wl}{2\,I}$$

$$\text{but } I = \frac{bd^3 - b'\,d'^3}{12}$$

$$I = \frac{5 \times 12^3 - 4{\cdot}65 \times 10{\cdot}88^3}{12}$$

$$I = 220{\cdot}95$$

$$\text{and } \delta = 6, \text{ and } W = \tfrac{43}{12} \times 2 \times 1\tfrac{1}{2} = 10{\cdot}75 \text{ tons}$$

$$\text{and } l = 43 \text{ inches}$$

$$\therefore S = \frac{6 \times 10\tfrac{3}{4} \times 43}{2 \times 220{\cdot}95} = 6{\cdot}27 \text{ tons}$$

that is, the maximum stress on each square inch in section is 6·27 tons. This section may therefore be safely used, as it gives a factor of safety of nearly $\frac{1}{6}$th, and an amount of stiffness is undoubtedly acquired by being embedded in concrete, as shown in Figures 54 and 55.

Grillage Foundations.—In the case of piers, steel joists are placed in two systems crossing each other. This arrangement is termed a grilled foundation. The space between the joists is then filled in with concrete, care being taken to work the same well in between the flanges.

Figures 56 to 58 show the method of constructing a grilled foundation, the weight of the building being supposed to be transmitted to the ground through piers.

EXAMPLE: Let a wall be supported on pillars 12 feet centres, the distributed load per lineal foot being 15 tons; therefore, the weight upon each pillar will be 180 tons—that is, there will be the same total stress upon the lower system of joists as in the 5 in. × 12 in. joists of the preceding example, if arrangements are made to distribute the stresses. Determine, therefore, the section required for the upper system, the factor of safety to be not less than $\frac{1}{3}$, the ultimate resistance of the steel joists being 32 tons. The lower system may be arranged as in the last example.

This is practically a case of a beam fixed at both ends under a distributed load with spans of 10 feet, as shown in Figure 57.

From the manufacturer's list is taken a steel joist 7 in. × 9 in., flanges ·81 thick, web ·77 thick, and I = 216·81.

The length of the beam, as shown in Figure 57, may be taken as 10 feet, and the distributed load as 15 tons per lineal foot, the 2 feet under the pillar being considered as under direct compression.

$$\therefore \text{ total distributed load on each of the three girders } = \frac{10 \times 15}{3} = 50 \text{ tons.}$$

Fig. 54.

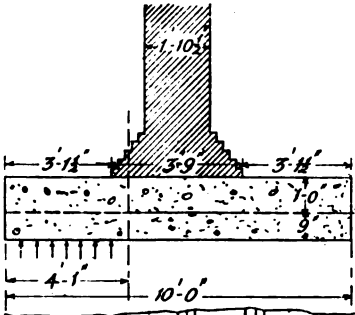
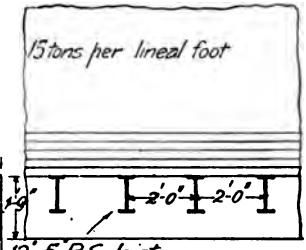


Fig. 55.



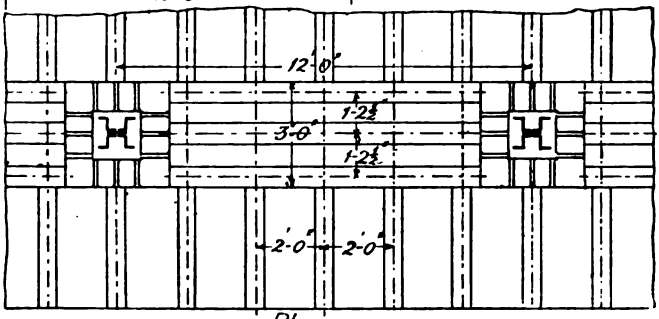


Fig. 56.

— Plan. —

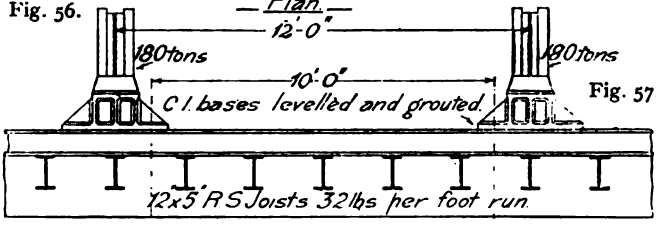
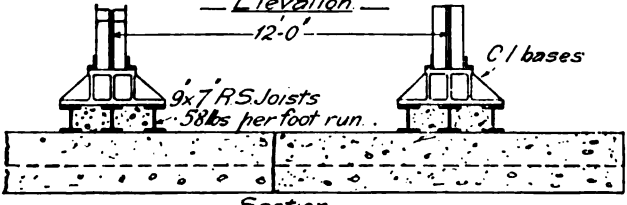


Fig. 57.

— Elevation. —



— Section. —

Fig. 58.

By the formula—

$$\therefore \frac{wl^3}{12} = \frac{C\,I}{\delta}$$

$$\therefore \frac{Wl}{12} = \frac{C\,I}{\delta}$$

$$\therefore C = \frac{\delta W l}{12\,I}$$

$$C = \frac{4{\cdot}5 \times 50 \times 120}{12 \times 216{\cdot}81}$$

$$= 10{\cdot}3 \text{ tons per square inch.}$$

Figures 56 to 58 illustrate this example, and give all the necessary details.

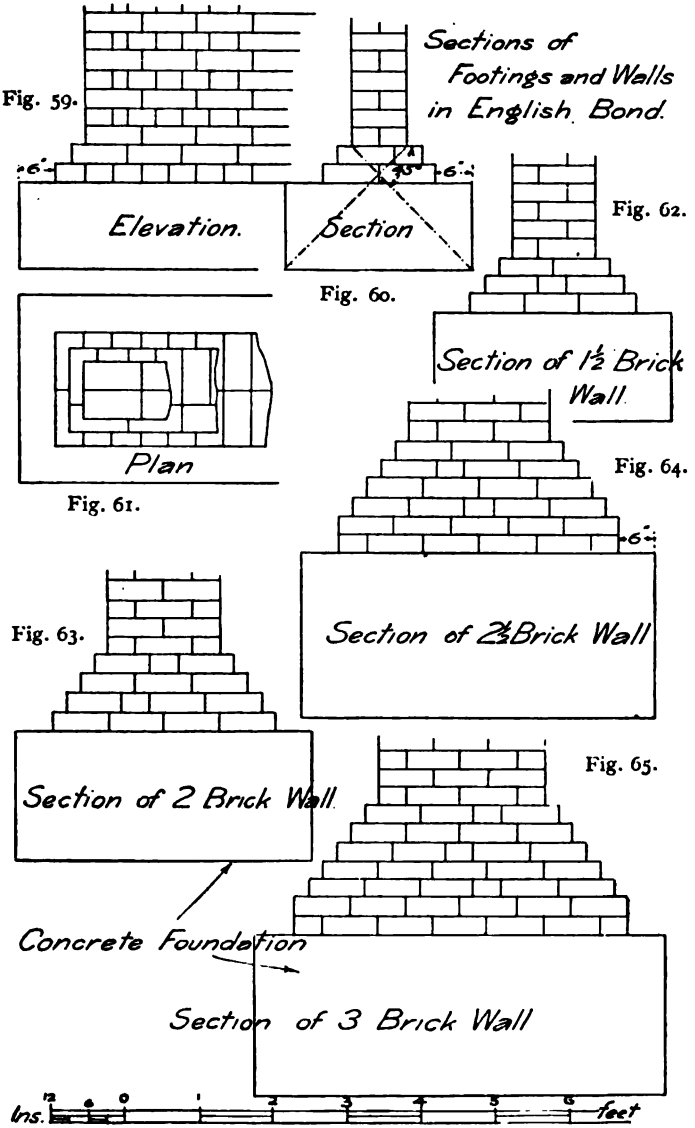
The bye-laws of the London County Council include the following provision as to the least dimensions of the concrete foundation :—

The foundations of the walls of every house or building shall be formed of a bed of good concrete not less than 9 *inches thick*, and projecting at least 4 inches on each side of the lowest course of footing of such walls. If the site be upon a natural bed of gravel, concrete will not be required.

Footings.—These are the wide courses placed at the base of a wall to distribute the pressure over a greater area of ground. The course coming immediately upon the concrete is required by the Model Bye-laws to be twice the required width of the wall; thus, in a two-brick wall this course would be four bricks wide. Offsets of $2\frac{1}{4}$ inches are then made on each side of each successive course till the desired thickness is obtained. Walls of two or more bricks in thickness frequently have their bottom courses of footings doubled, as shown in Figures 64 and 65.

Care should be taken that the bricks in footings should be laid as far as possible as headers, but if stretchers are required in any course they should be laid near the centre of the wall.

Figures 59 to 65 give sections of footings and walls in



Figs. 59–65. Sections of Footings and Walls in English Bond.

English bond from one to three bricks in thickness. Trenches in practice are excavated for beds of concrete from 9 inches and upwards in depth, and 12 inches wider than base of footings (6 inches on each side).

Seddon recommends that brick footings be dispensed with, and a deep bed of good cement concrete substituted for the footings and concrete foundation; where ballast is found on the site this is often a more economical practice.

The following weights of different earths are given by Newman:—

Name of Earth.	Weight	
	Decimals of a Ton. Cubic Foot.	Tons. Cubic Yard.
Basalt, solid	0·083	2·25
Bath stone, solid	0·052	1·40
Chalk, damp to wet, loose to close ...	0·056 to 0·074	1·50 to 2·00
Clay	0·054 to 0·059	1·45 to 1·60
Flint, solid	0·074	2·00
Granite	0·078	2·10
Gravel and shingle	0·046 to 0·055	1·25 to 1·50
Limestone (lias to compact mountain)	0·067 to 0·078	1·81 to 2·10
Marl	0·044 to 0·052	1·20 to 1·40
Mud, at surface	0·044	1·20
Mud, at about 15 feet in depth ...	0·048	1·30
Peat, hard, and top mould	0·036	0·98
Portland stone, solid	0·065	1·75
Quartz, solid	0·076	2·05
Sand, dry river	0·041	1·10
Sand, damp and shaken	0·055	1·50
Sandstone, solid	0·063 to 0·072	1·70 to 1·95
Shale	0·074	2·00
Slate, solid	0·080	2·15
Trap, solid	0·078	2·10

CHAPTER II.

BRICKWORK.

Definition.—Brickwork is the art of arranging and bedding bricks in either lime or cement mortar, to unite them and form a homogeneous mass of a desired shape with sufficient stability to safely resist the stresses to which it is to be subjected.

Dimensions of Bricks.—The average size of a good

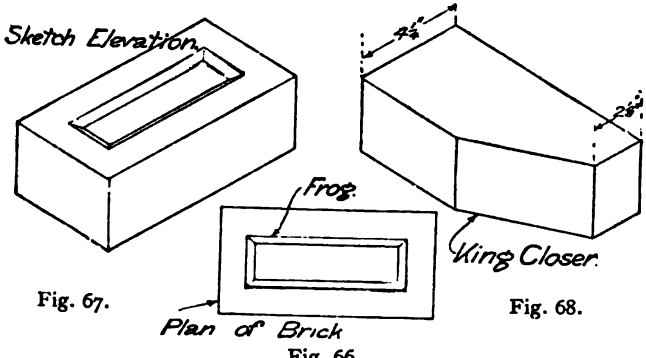


Fig. 67. Fig. 68.

Fig. 66.

London stock brick is about $8\frac{5}{8}$ inches long, $4\frac{1}{8}$ inches wide, and $2\frac{5}{8}$ inches thick. The dimensions, including one mortar joint, in this work, unless otherwise stated, will be taken as, length 9 inches, width $4\frac{1}{2}$ inches, and thickness 3 inches. To obtain a perfect bond in brickwork two headers plus one mortar joint should equal one stretcher; the thickness varies

greatly in different districts: in the neighbourhood of London it is usually arranged to work four courses including the bed joints to equal 1 foot. The thickness of each of the mortar joints is generally $\frac{3}{8}$ths of an inch. Bricks are usually bedded on the 9 in. × $4\frac{1}{2}$ in. surface in lime or cement mortar, the top surface having an indentation, or frog, as it is sometimes called, which affords a good key for the mortar, as shown in Figures 66 and 67.

In the north of England, bricks are often made up to 4 inches in thickness. For partition walls, special bricks 6 inches in width are made.

Bedding of Bricks.—Bricks are bedded in mortar, 1st, to distribute the pressure more evenly over the bricks; 2ndly, to obtain adhesion and thus give homogeneity to the mass; 3rdly, by filling up the interstices, to make the walls weather-proof.

Bricks are wetted or soaked before being used in order to remove loose dust, to afford better adhesion for the mortar, and to prevent the bricks absorbing too much moisture from the mortar.

Mortar.—The mortar is composed of one of lime to two or three parts of sand, or from one of Portland cement to one to four of sand. Lime mortar sometimes has cement added to it to increase its strength and hasten its setting.

Lime mortar should not be used when fresh nor in an untempered condition, as in that state its cohesive value is small and it is difficult to work; but after making should be left two days at least, then turned over and beaten up again.

This tempering gives it the property of working evenly and fat. Cement mortar should be used as soon after making as possible, as the setting action commences immediately after mixing and any further working-up of the mortar lowers its ultimate strength.

Building during Frosty Weather.—All brickwork should

be suspended during frosty weather, as its stability is endangered by the disintegration of the mortar by the frost while it is wet. When the work is urgently required it should be carried up in cement mortar in the intervals between the frost; but all the freshly-built portions should be carefully covered and protected on any recurrence of the frost.

Technical Terms.—*Course* is the name given to the row of bricks between two bed joints, the thickness is taken as one brick plus one mortar joint, in this work; unless otherwise stated, it will be considered as 3 inches or, as technically described, four courses to the foot.

Bed Joints.—The mortar joints between the courses opposed to the pressure.

(*a*) In walls with vertical faces the bed joints would be horizontal.
(*b*) In batter walls they would be at right angles to the batter.
(*c*) In arches they come between the voussoirs.

Quoins.—The external corners of walls. The name is sometimes applied to the bricks or stones which form the quoins, *e.g.*, quoin brick, quoin stone.

Perpends.—The vertical joints of the face of the wall. Where they fall immediately over each other in alternate courses, the perpends are said to be kept.

Stretchers.—Bricks laid with their lengths of 9 inches on the face of the wall or parallel to the face of the wall.

Headers.—Bricks laid with the width of $4\frac{1}{2}$ inches on the face of the wall or parallel to the face of the wall.

Bats.—Pieces of bricks, usually known, according to their fraction of a whole brick, as $\frac{1}{2}$ or $\frac{3}{4}$ bats.

Lap.—The horizontal distance between the vertical joints in two successive courses. This should be $2\frac{1}{4}$ inches, or one quarter of the length of the brick.

Queen Closers.—Bricks made the same length and thickness as ordinary bricks, but half the width. It is not usual

to make queen closers in one piece, owing to the difficulty in cutting. There are always a large number of bricks broken in the cartage and bricklayers form the closers economically by cutting their broken bricks into $\frac{1}{4}$ brick bats and placing two together to form closers, as shown in Figures 71 to 79. This is easier and not nearly as wasteful as cutting an ordinary brick lengthwise in two.

King Closers.—Bricks cut so that one end is half the width of the brick, as shown in Figure 68. They are used in positions where the full width is required at the back to properly form the bond. They usually occur at rebated openings in Flemish bond walls.

Bond (that is, to bind), the name given to any arrangement of bricks in which no vertical joint of one course is exactly over the one in the next course above or below it, and having the greatest possible amount of lap.

Bonds in Brickwork.—Bond in brickwork is the method of arranging each brick so that it laps over the bricks with which it is in contact above and below a distance equal to one quarter of the length of the brick. To ensure good bond the following rules should be rigidly adhered to:—1st, the arrangement of the bricks must be uniform, and as few bats as possible be employed; 2ndly, a closer to be inserted after the quoin header in any course; 3rdly, the vertical joints in every other course to be perpendicularly in line on the internal as well as the external face; 4thly, stretchers are only to be used on the faces of the wall, the interior to consist of headers only, except in footings and corbels; 5thly, the dimensions of bricks should be such that when bedded the length should equal twice the width plus a mortar joint.

Facing Bond.—Hindrances to good bond often occur when facing bricks used are costly or of different lengths and widths to the body of the wall; in 9-inch walls, where it is necessary to have two fair faces, very frequently facing

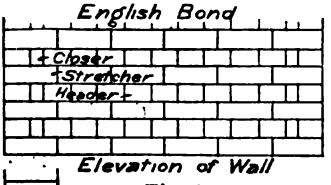


Fig. 69.

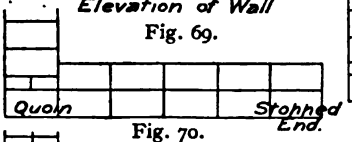


Fig. 70.

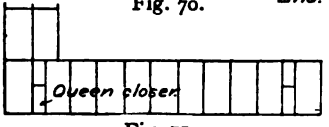


Fig. 71.

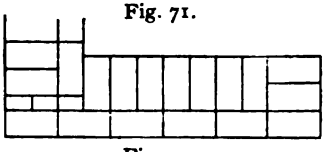


Fig. 72.

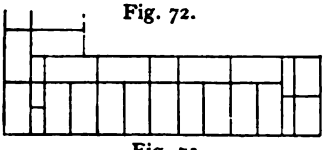
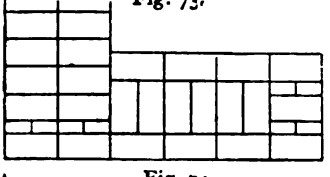


Fig. 73.



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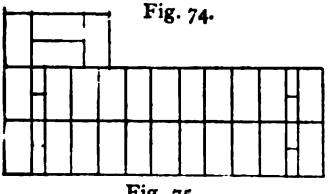


Fig. 75.

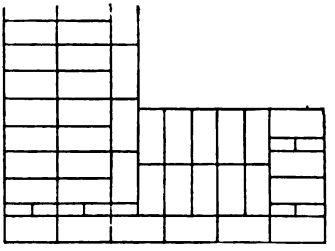


Fig. 76.

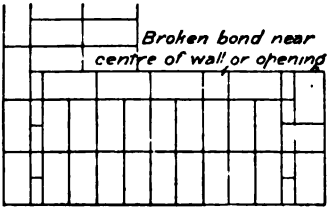


Fig. 77.

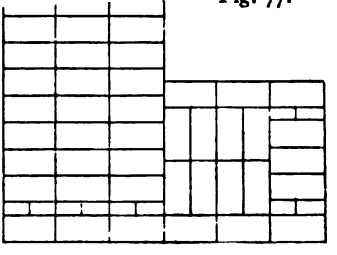


Fig. 78.

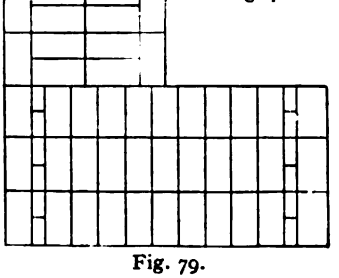


Fig. 79.

Figs. 69–79. Examples of English Bond.

headers are cut off, being an easy as well as a cheap method of overcoming the difficulty; but this weakens the wall to a large extent, and it would be better to bond in only every third or fourth course; a method known as facing bond as shown in Figure 107.

There are several kinds of bond used in brickwork. Those described in this chapter being as follows:—1st English, 2nd Double Flemish, 3rd Single Flemish, 4th English Cross, 5th Dutch, 6th Stretching or Chimney, 7th Heading Bond, 8th Sussex Bond, 9th Raking Bonds, 10th Hoop Iron.

English Bond.—When the bond is arranged as shown in elevations and plans, Figures 69 to 79, it is known as English bond, and sometimes old English bond. It consists of one course of headers and one course of stretchers alternately. In this bond bricks are laid as stretchers only on the boundaries of courses, thus showing on the face of the wall, and no attempt should be made to break the joints in a course running through from back to front of a wall. That course which consists of stretchers on the face is known as a stretching course, and all in course above or below it would be headers with the exception of the closer brick, which is always placed next to the quoin header to complete the bond, and these courses would be called heading courses.

It may be noticed that in walls the thickness of which is a multiple of a whole brick, the same course will show either—

(*a*) Stretchers in front elevation and stretchers in back elevation.
(*b*) Headers " " " headers " "

but in walls in which the thickness is an odd number of half bricks, the same course will show either—

(*a*) Stretcher in front elevation and header in back elevation.
(*b*) Header " " " stretcher " "

In setting out the plan of a course to any width, draw the quoin, or corner brick; then next to the face (which in front elevation shows headers) place closers to the required thickness of wall, after which set out all the front headers, and if the thicknses is a multiple of a whole brick, set out headers in rear; if the thickness is an odd number of half bricks, set out stretchers in rear: the intervening space, if any, is always filled in with headers.

Double Flemish Bond has headers and stretchers alternately in the same course, both in front and back elevations, as shown in Figures 80 to 90. It is weaker than English bond, owing to the greater number of bats and stretchers, but is considered by some to look better on the face. It is also economical, as it admits of a greater number of bats being used, so that any bricks broken in transit may be utilised. By using double Flemish bond for walls one brick in thickness, it is easier to obtain a fair face on both sides than with English bond.

Single Flemish Bond consists in arranging the bricks as Flemish bond on the face, and English bond as backing. This is often done on the presumption that the strength of the English bond as well as the external appearance of the double Flemish is attained, but this is questionable. It is generally used where more expensive bricks are specified for facing. The thinnest wall where this method can be introduced is 1½ brick thick. Plans of alternate courses are given, Figures 91 to 99. The front elevations are the same as in double Flemish bond.

English Cross Bond.—A class of English bond. Every other stretching course has a header placed next the quoin stretcher, and the heading course has closers placed in the usual manner.

Dutch Bond.—In every alternate stretching course a header is introduced as the second brick from the quoin, three-quarter bricks are used in the remaining stretching courses at the quoins, and the closers are dispensed with in

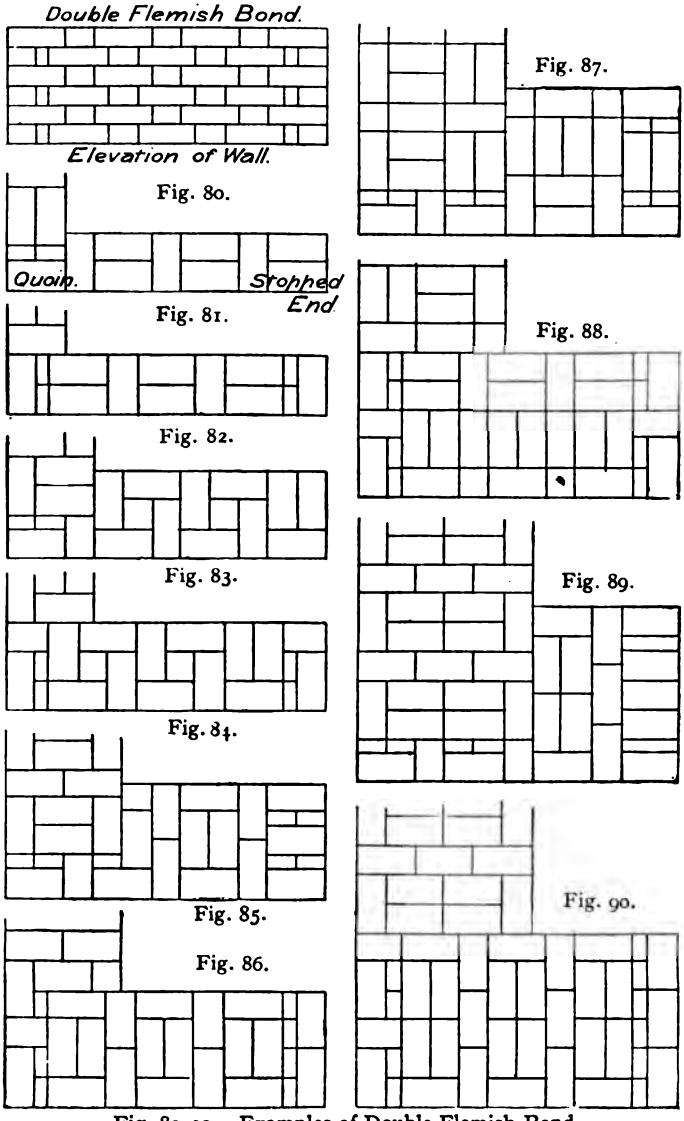
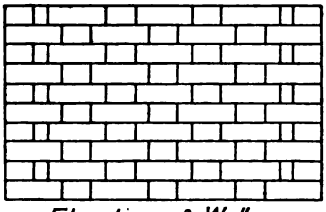


Fig. 80–90. Examples of Double Flemish Bond.

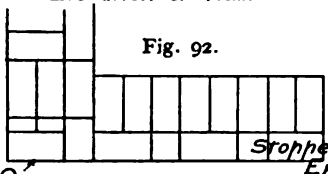
Fig. 91.

Single Flemish Bond.



Elevation of Wall.

Fig. 92.



Stopped End

Quoin

Fig. 93.

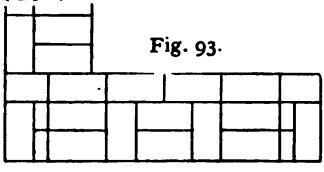


Fig. 94.

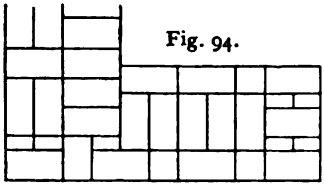


Fig. 95.

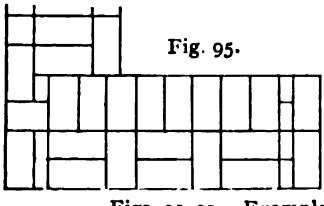


Fig. 96.

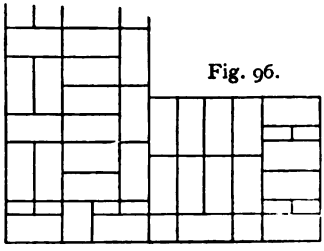


Fig. 97.

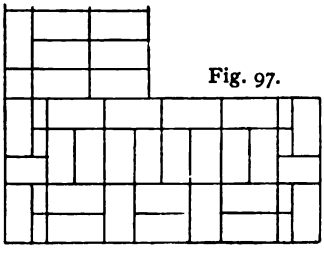


Fig. 98.

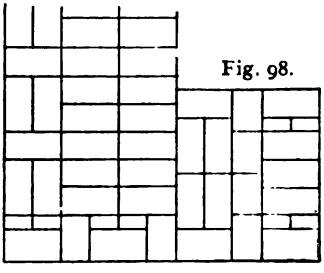
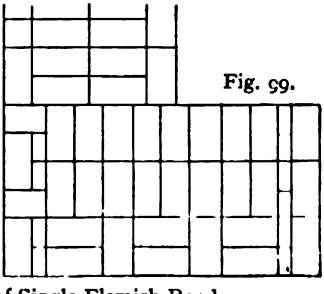


Fig. 99.



Figs. 91–99. Examples of Single Flemish Bond.

the heading courses, as shown in Figures 100 to 105; the longitudinal tie becomes much greater, and the appearance of the elevation is certainly superior to much of the inferior work one is accustomed to see as examples of the modern bricklayer's skill in bonding. Should there be a fracture, it is supposed to throw it more obliquely.

Stretching Bond should be used only for walls half brick thick, as for partition walls. All bricks are laid as stretchers upon the face.

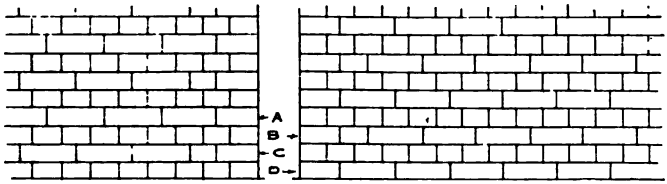
Heading Bond.—All bricks show as headers on face. Used chiefly for rounding curves, for footings, corbels and cornices.

Garden or Boundary Wall Bond, Sussex Bond, Scotch Bond, are the names given to walls built with three stretchers and one header in same course, constantly recurring, as shown in elevation, Figure 106. This method is used for walls one brick thick that are seen on both sides, as it is easier to adjust the back face by decreasing the number of headers, the lengths of which usually vary.

Hoop-Iron Bond.—An additional longitudinal tie termed "*hoop-iron bond,*" is often inserted in walls, being usually pieces of hoop iron 1 in. by $\frac{1}{16}$ in., one row for every half brick in the thickness of the wall, as shown in Figure 108. It should be carefully tarred and sanded or galvanized before using, to prevent oxidation. It is hooked at all angles and junctions, as shown in Figures 109 and 110. If bedded in two courses in cement, additional strength is gained; piecces of hoop iron may be used with advantage where the bond at any part of the wall is defective.

Raking Bonds.—Walls as they increase in thickness increase in transverse strength; but become proportionally weaker in a longitudinal direction, owing to the fact that stretchers are not placed in the interior of a wall. This defect is remedied by using raking courses at regular intervals of from four to eight courses in the height of a

Fig. 100. Dutch Bond Fig. 101.



Elevation on Return. Elevation

Fig. 102. Course A. Course B. Fig. 103.

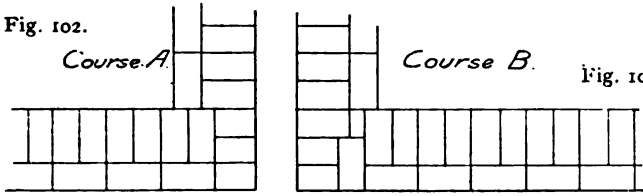
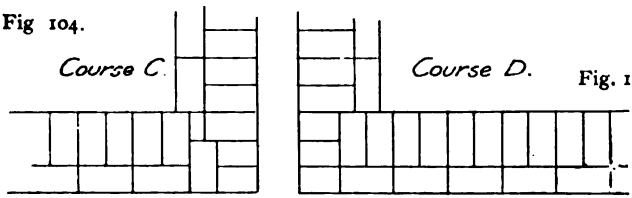
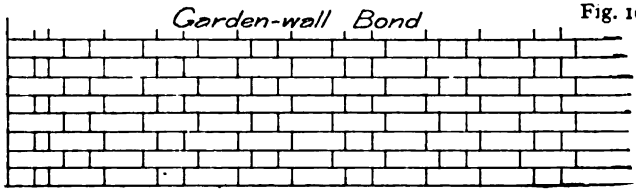


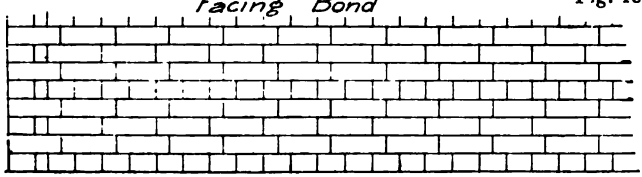
Fig 104. Course C. Course D. Fig. 105.

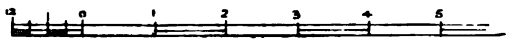


Garden-wall Bond Fig. 106.



Facing Bond Fig. 107.





Figs. 100–107.

wall. The joints of bricks laid in this position cannot coincide with the joints of the ordinary courses directly above or below, the inclination to the face usually being determined by making the extremities of the diagonal of two, three or more bricks coincide with the backs of the facing bricks. It is not advisable to use one raking course directly above another, as there is always a weakness with the face bricks at the junction of the raking.

Raking bonds are always placed in the stretching courses in walls of an even number of half bricks in thickness, in order that their influence may extend over a

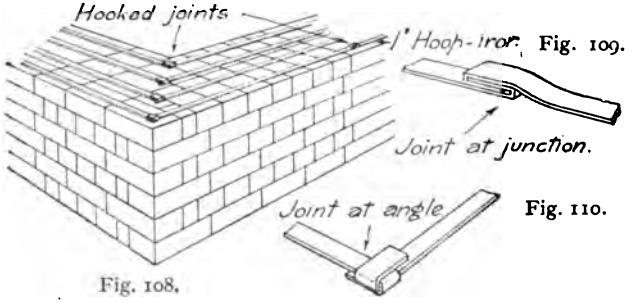


Fig. 108. Fig. 109. Fig. 110.

greater area than would be the case if they were placed in the heading courses.

The alternate courses of raking bonds should be laid in different directions, in order to make the tie as perfect as possible.

There are two varieties of raking bonds, viz., diagonal and herring-bone.

Diagonal Bond.—This is used in the thinner walls, *i.e.*, between two and four bricks in thickness. The operation is as follows :—The face bricks are laid, one or more bricks (in the latter case placed end to end) are bedded between the face bricks, so that the opposite corners touch the

latter, this determines the angle that the bricks should be laid, the triangular spaces at the ends of the bricks being filled up with small pieces of brick cut to shape, as shown in Figure 111.

Herring-bone Bond.—The bricks in this method are laid at an angle of 45°, commencing at the centre line and working towards the face bricks. Herring-bone bond is used for walls four bricks and upwards in thickness. Figure 112 shows this method.

Diagonal and herring-bone patterns are often used to form ornamental panels in the face of walls, and also in floors paved with bricks.

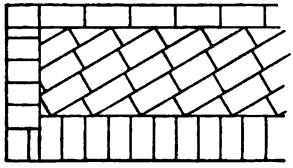


Fig. 111.

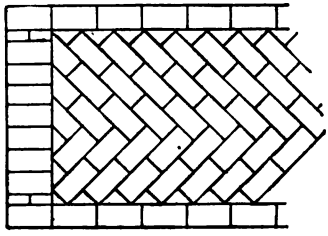


Fig. 112.

Junctions of Cross Walls.—The bond is obtained in cross or party walls abutting against main walls by placing a closer $4\frac{1}{2}$ inches from the face in every alternate course in the main wall, thus leaving a space $2\frac{1}{4}$ inches deep and of a length equal to the thickness of the cross wall for the reception of the $2\frac{1}{4}$ inch projection in every other course of the cross wall, as shown in Figures 113 to 118.

Figures 119 and 120 illustrate the junction of one-and-a-half brick Flemish bond with one brick English bond.

Reveals.—The vertical sides of window or door openings between the face of wall and window or door frames. The horizontal distance between is the clear span of opening.

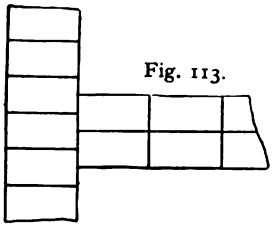


Fig. 113.

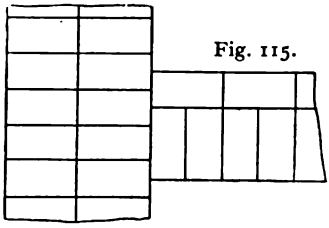


Fig. 115.

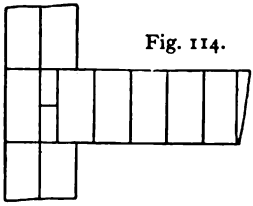


Fig. 114.

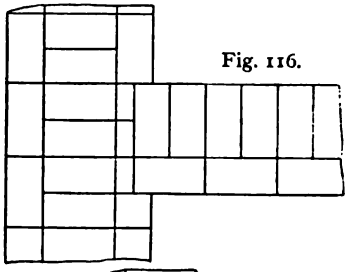


Fig. 116.

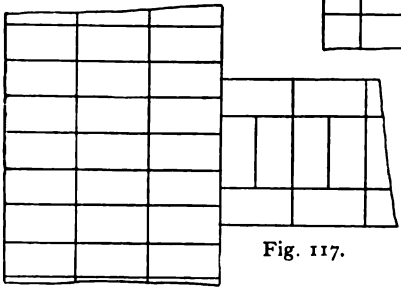


Fig. 117.

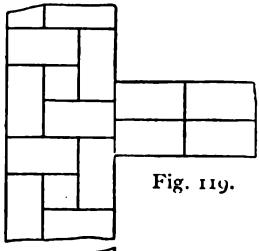


Fig. 119.

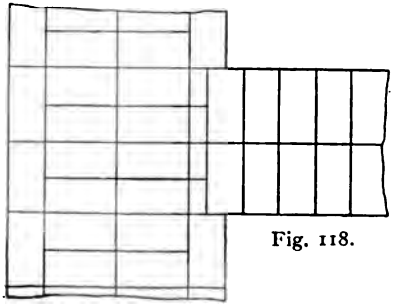


Fig. 118.

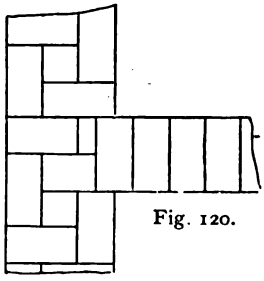
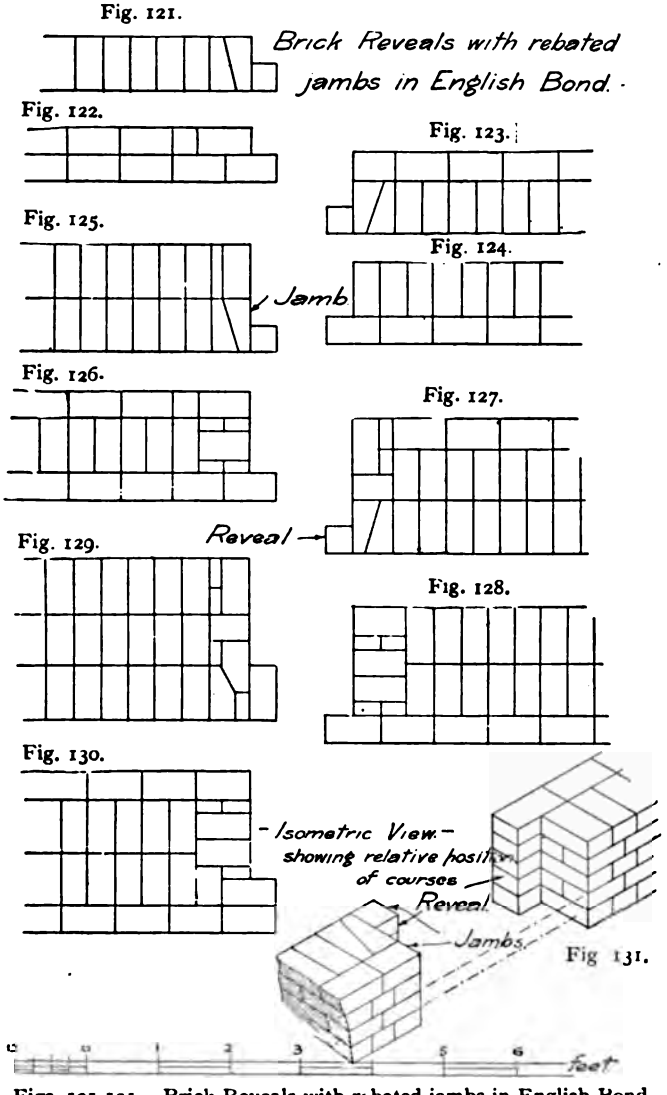


Fig. 120.

Figs. 113–120. Junctions of Cross Walls.



Figs. 121-131. Brick Reveals with rebated jambs in English Bond.

Jambs are the vertical sides of an opening, and in rebated window or door openings there are the internal jambs and the external jambs, the latter being known as the reveals.

Internal jambs are usually covered with plaster, or wood linings.

Figures 121 to 131 show brick reveals, with rebated jambs in English bond.

Splayed Jambs.—The internal jambs of windows occurring in thick walls are often splayed to obstruct as little light as possible. Figures 141 and 142 show the method of bonding two alternate courses of a three-brick wall, built in single Flemish bond. In inferior work splayed jambs are often formed by simply constructing a number of square offsets.

Squint Quoins.—External angles other than a right angle in plan are called squint quoins. Such require considerable care in the planning, as different angles require special modifications of the principles of bonding.

Two general rules should be kept in view, viz., (1) no bird's-mouth joint in plan should be employed, except on the face of the work in acute angular quoins, where it is at times absolutely necessary. They would be useful in the interior in some cases, but sufficient care is not usually taken in cutting the re-entering angle where the brick is not exposed to view, the latter generally becoming cracked or broken, as bricks do not lend themselves to be easily cut in this manner. (2) All small pieces should be avoided, the bricks being as nearly as possible whole, and only having sufficient cut off to adapt them to the plan. Closers are not always necessary in obtuse angles; better work is produced where they can be superseded. It is evident that the quoin stretcher can never show its full length on either face. Advantage should therefore be taken, if the angle is not too great, to show three-quarters

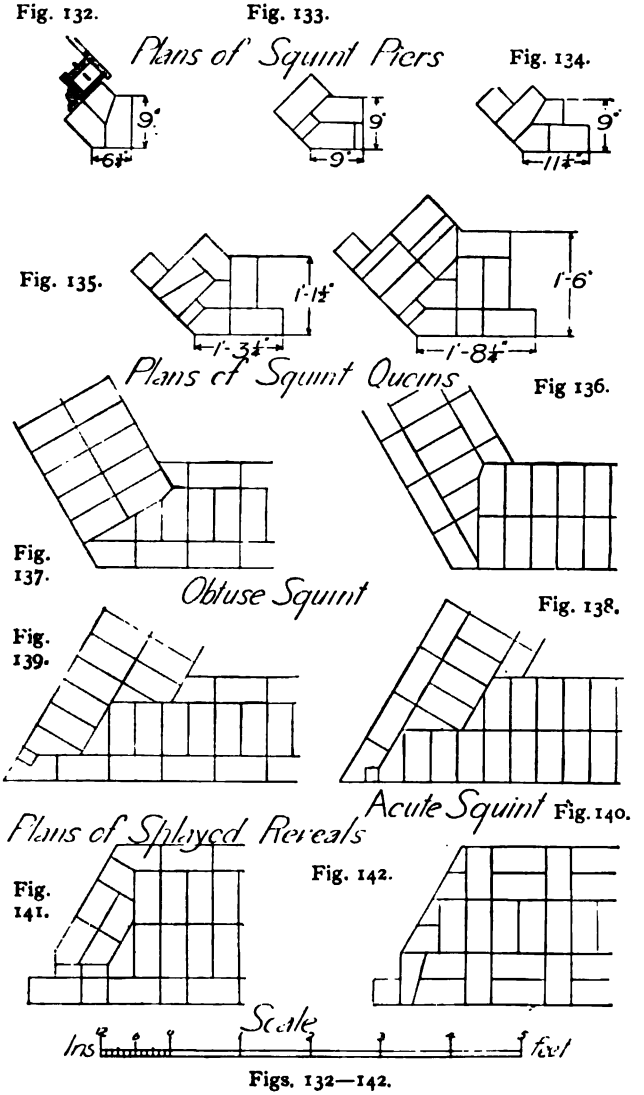


Fig. 132.
Fig. 133.
Plans of Squint Piers
Fig. 134.
9"
6¼"
9"
9"
9"
11¼"
Fig. 135.
1'-1½"
1'-3¼"
1'-6"
1'-8¼"
Plans of Squint Quoins
Fig 136.
Fig. 137.
Obtuse Squint
Fig. 138.
Fig. 139.
Acute Squint
Fig. 140.
Plans of Splayed Reveals
Fig. 141.
Fig. 142.
Scale
Ins
feet

Figs. 132—142.

of a brick at the quoin, as shown in Figures 137 and 138, thus obviating the necessity of a closer to gain the proper $2\frac{1}{4}$ inch bond; but in acute angles, the quoin stretcher can always be obtained in its full length, as shown in Figures 139 and 140.

Figures 132 to 136 show the methods of constructing squint piers, such as would be employed in the angles of bay windows.

Toothing.—The usual method of leaving a brick wall which is to be continued at some future time is to tooth it, which consists in leaving each header projecting $2\frac{1}{4}$ inches beyond the stretching courses above and below to allow the new work to be bonded to the old as shown in Figure 144.

The usual practice in joining new cross walls to old main walls is to cut out a number of rectangular recesses in the main walls equal in width to the width of the cross wall, three courses in height, and half a brick in depth, a space of three courses being left between the sinkings (as shown in Figure 143); the new cross wall is then bonded into the recesses with cement mortar to avoid any settlement. It is necessary that the sinkings should not be less than 9 inches apart, as in the cutting the portion between is likely to become shaken and cracked.

Racking.—Racking is the term applied to the method of arranging the edge of a brick wall, part of which is unavoidably delayed while the remainder is carried up. The unfinished edge must not be built vertically or simply toothed, but should be set back $2\frac{1}{4}$ inches at each course, to reduce the possibility and the unsightliness of defects caused by any settlement that may take place in the most recently built portion of the wall.

Also where new walls are erected the usual method of procedure is to build what is technically termed a corner, that is, the angles or the extremities of the walls, to a height

Fig. 143.

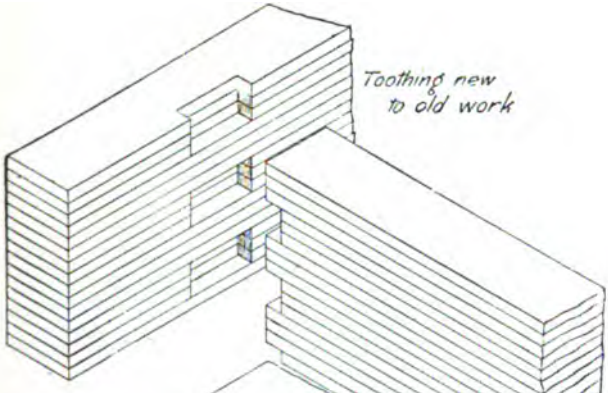


Fig. 144.

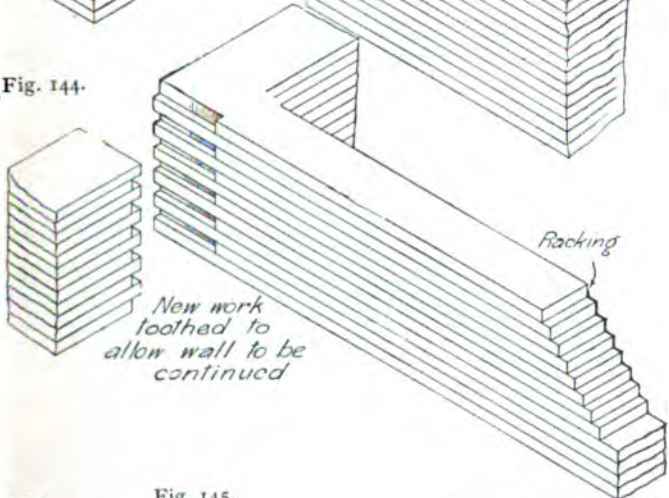
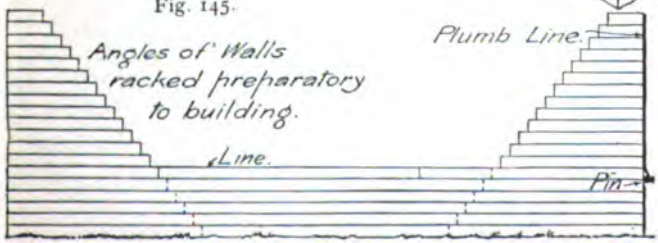


Fig. 145.



of two or three feet, the angle bricks being carefully plumbed on both faces. The base of the corner is extended along the wall, and is racked back as the work is carried up, as shown in Figure 145. The intermediate portion of the wall is then built between the two corners, the bricks in the courses being kept level and straight by building their upper edges to a line strained between the two corners.

Levelling of Brickwork.—In bedding bricks, great care should be taken to keep all courses perfectly level. To do this, the footings and the starting course should be carefully levelled through, using a level at least 10 feet in length, commencing at one end and levelling towards the other, and taking care to reverse the level each time at each forward step, and completing the length to be levelled in an even number of steps. A piece of slate or iron is left projecting from the lowest course, and from this all other courses at the corners can be levelled by using the gauged rod, which is usually about 10 feet in length, with the courses marked on it. The work should then be again tested by the level, and the operation repeated.

Joints.—Bricks and stones are bedded with mortar for two purposes, viz., to cause the bricks to adhere to each other, and to distribute the pressure uniformly over the whole bed where the beds of the bricks or stones are irregular. Great care should be taken that both the bed and side joints are thoroughly flushed, or filled up with mortar. This is done in three ways: (1) by the trowel; (2) by larrying; (3) by grouting. The first method is that usually adopted in all thin walls. The second, larrying, is largely adopted in thick walls. The face bricks are first laid; the mortar, in a semi-fluid condition, is then poured into the space between the face bricks; the bricks are then pushed rapidly horizontally for a short distance into their position; a certain amount of the mortar is thus displaced, this rises in the side joints, and completely fills all the

interstices; should the mortar not rise to the top of the joints, the vacant spaces are filled up, when the next course is larried. (3) Grouting is an operation used in brickwork, generally for gauged arches and similar work, where fine joints are required; it consists in mixing the mortar to a fluid condition, of about the consistency of cream, this being poured into the joints of the work after the latter has been placed in position. Figure 407, in the drawing of flat gauged arch voussoir, shows a channel prepared for grouting.

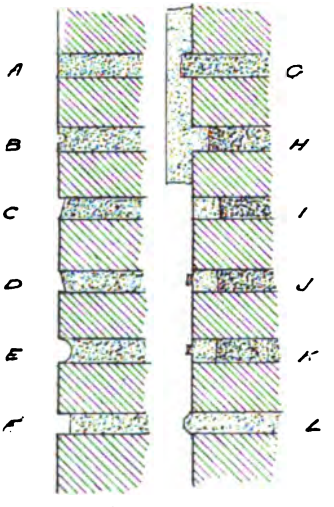


Fig. 146 *a* to *l*.

Joints on Face.—The joints on the face of work are finished in a variety of ways, as shown in Figures 146 *a* to *l*, to increase the effect, and to resist the weather; they may be finished as the work proceeds, or as the scaffold is taken down on the completion of the building; the former is the stronger and more durable, the latter is cleaner and has a better appearance, and is rendered necessary when the work has been built during frosty weather; where the latter method is employed, the joints should be raked out for at least $\frac{1}{2}$ inch in depth as the work proceeds. The joints in new work should be clean, sharp and regular; but no fancy pointing is permissible. Figures 146 *a* to *l* show the forms of joints applied to brickwork.

Flat or Flush Joints.—This is formed (as shown in Figure 146 *a*) as the work proceeds by pressing with the

trowel the wet mortar that protrudes beyond the face, flat and flush with the wall.

Flat Joint Jointed.—This is formed similarly to the above (as shown in Figure 146 *b*), but has in addition to the previous joint a semi-circular groove run along the centre of each joint, with a jointing tool and straight-edge. This has the effect of making the mortar more dense.

Struck Joints.—This is formed by pressing with the trowel the mortar along the upper edge of the joint slightly below the surface, as shown in Figure 146 *c*. This is a good joint, as the upper edge of the mortar is protected, and any water is thrown off with facility; its appearance is good, as it presents a sharp shadow at every horizontal joint, and forms the method of finishing new work; it is sometimes called a weather-struck joint. The mortar is often ignorantly struck back on the lower edge, as shown in Figure 146 *d*, under the impression that the appearance is enhanced thereby, the idea being that a sharp line is presented on the upper edge of the bricks, but as no shadow is formed, the effect is lost at a few feet above the eye, a ledge is formed on which the water lodges, which freezes in the winter, and rapidly destroys the upper edges of the bricks and the joint.

Keyed Joint, as shown in Figure 146 *e*, is formed by drawing a jointing tool with a curved edge, the same width as the joint, along the latter; it has the effect of making the mortar dense at this part, and improves the appearance by making the joints distinct. It is not much used.

Keyed joints of the form shown in Figures 146 *g* and *h* are employed where the wall is to be rendered. In the first case, the mortar in the joints is left protruding; in the second, they are raked out.

Recessed Joint.—This is used to obtain a pleasing and deep shadow, but care must be taken that the bricks are

hard and unlikely to be damaged by the weather. It is the joint employed in the new Church House, Westminster. Figure 146 *f* gives this joint.

Pointing Old Works.—This operation consists in raking out the decayed mortar from the joints to a depth of at least $\frac{3}{4}$ inch, and in filling the same with cement, or some hard-setting mortar, as shown in Figure 146 *i*. The joints may be finished in any of the methods stated, or by one of the two methods known as tuck and bastard tuck pointing, which are fancy forms adopted by bricklayers to increase the effect by forming sharply defined joints.

Tuck Pointing, as shown in Figure 146 *j*, consists in filling up the raked-out joints flush with a stopping of cement or some hard mortar. The joints in this condition generally appear very wide, owing to the edges of the bricks being ragged, this being due to the frost or to the clumsy method in which the joints have been raked. The whole front, joints included, is then coloured with a compound of copperas, and a pigment of the colour required, or the front is rubbed with a piece of soft brick till the bricks and joints are of one colour. While lime putty is pressed on to the joints in straight lines, with a jointer worked on a bevelled edge straight-edge; and before the latter is removed, the edges are trimmed with a tool called a Frenchman, which usually consists of an ordinary table knife with the end of the blade turned up at right angles to the remainder. The edge of the knife cuts the putty, and the turned-up end drags off the superfluous stuff, leaving a white joint $\frac{1}{4}$ inch in width, and $\frac{1}{16}$ inch in thickness on the face of the work. This is not the best method of pointing if the bricks are sound and their edges sharp and regular; but if the edges are broken, the joint, when stopped, appears very wide and irregular, and is thought by some not to look well if the above process were not adopted. This method should never be permitted.

Bastard Tuck Pointing is the name given when a ridge $\frac{1}{4}$ inch to $\frac{3}{8}$ inch is formed on and of the stopping itself, as shown in Figure 146 *k*.

Masons' V Joint.—Figure 146 *l* shows the usual joint used for masons' work.

Damp-proof Courses.—Walls are liable to become damp in three ways: 1st, by a driving rain, in which case the damp passes through the face of walls; 2ndly, by damp passing down through the top of walls; 3rdly, by damp rising up the wall from the ground, or being forced through the walls of the sub-structure into the basement story.

In the first case, dampness may be prevented from making its way to the interior by building the walls sufficiently thick, by weather tilings, by rendering in cement, or by constructing hollow or cavity walls, as shown in Figures 149, 153, and 154.

2ndly. The walls may be kept dry by a coping of stone or dense vitrified bricks, as shown in Figure 155, by a layer of some damp-proof material, or both these methods combined.

3rdly. Dampness is prevented by placing a layer of some impervious material through the whole thickness of the wall above the ground line, as shown in Figure 147, and by forming a similar layer in a vertical position outside the wall or within its thickness, and covering the whole surface of the ground inside the building by such an impervious material, as shown in Figures 47 and 48.

There are five materials in general use for forming damp-proof courses, viz., sheet lead, slates set in cement, glazed stoneware, asphalte and weather-tiling for protecting vertical surfaces.

1. A very effective horizontal damp-proof course is obtained by placing a layer of sheet lead through the whole thickness of the wall, either directly below the coping stone, or from 6 inches to 1 foot above the ground

Fig. 147.

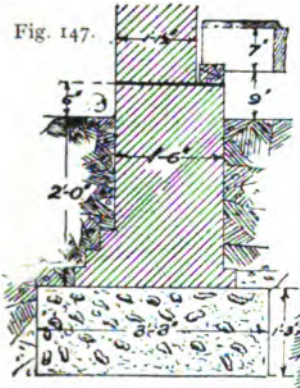


Fig. 148.

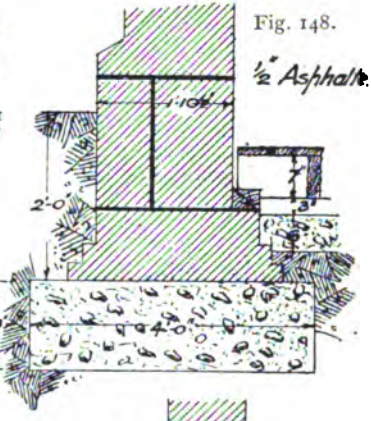


Fig. 149.

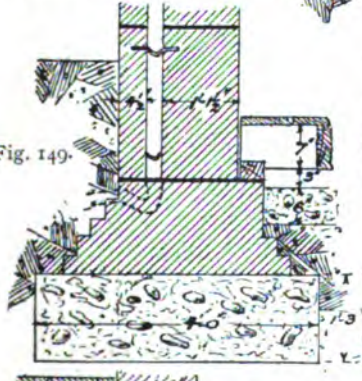


Fig. 150.

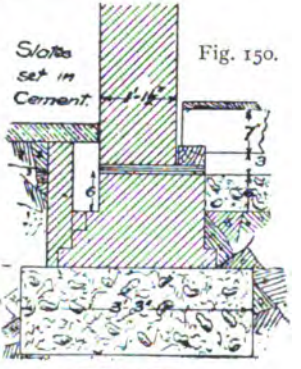


Fig. 151.

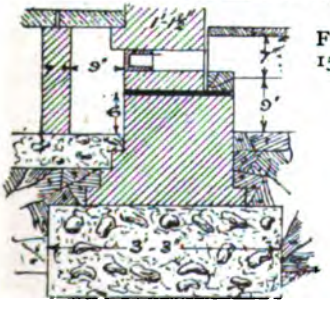
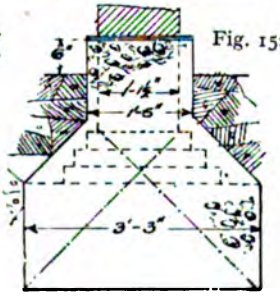


Fig. 152.



level. There is an objection that lead in the latter position, where it occurs under a heavy building, is liable to squeeze out to a certain extent; this is not sufficient to injure the lead, but the surface of the latter having become compressed and adapted to the rough surface of the stone in its movement about the outside edges, has the tendency to cause small pieces of the adjacent stone to spall; also the lead is subject to being decomposed by the CO_2 from the air and the lime in the mortar, and so converted into a basic carbonate. This action would take an enormous time to accomplish, and may, therefore, not be regarded as a great objection to the use of lead.

2. A cheap and efficient damp-proof course is formed by bedding two courses of slates in Portland cement, as shown in Figure 150; care must be taken to break the joint in the two courses of slates on all their sides. This method of forming a damp-proof course is also largely adopted to render brick copings damp-resisting; in this case they are made to project about 2 inches in order to throw all water clear of the wall, as shown in Figure 155, tiles being often used for this purpose, but are not so good as slate, as they are more porous. A course of slating or tiles set in this position is known as a creasing course. The coping placed above the slates may be either of special vitrified bricks or the ordinary bricks placed on their edges, and in each case should be bedded and jointed in cement. Damp-proof courses at the bases of walls, to comply with the Model Bye-Laws, are finished flush with the face of walls, and placed not less than 6 inches above the ground level, and six methods are shown in Figures 147 to 152 satisfying these conditions.

The courses of brickwork below the damp-proof course might with advantage be set in cement mortar.

Figure 152 is a section showing the excellent method of substituting Portland cement concrete for the brickwork

below the damp-proof course. The concrete is usually composed of 1 to 4, and the thickness of the wall is generally made one-third more than the minimum brick wall dimension, which latter is shown dotted in the figure.

3. Glazed stoneware slabs are often employed for damp-proof courses. They are made in sizes of 9 inches in width, about 2 inches in thickness, and 9 inches, 1 foot 1½ inches, and 1 foot 6 inches in length, the latter varying to suit the thicknesses of walls. The slabs are usually perforated in the direction of their length, which, below wood floors enhances their value, as they act as ventilating courses. It is important that the side joints of the slabs should be grooved, to prevent any moisture being drawn between the slabs by capillary attraction. These slabs are very hard and strong, thus rendering them valuable for heavy buildings in any climate. They are moulded to the shape required while the material is in a plastic condition, and burned as described in the article on Stoneware.

Asphalte.—Asphalte (described in the article on same) is largely used for damp-proof layers, both beneath the coping and at the bases of walls above the ground level. It is applied in layers of ½ inch in thickness throughout the thicknesses of walls, and also in an upright position either on the faces of walls or in their interior. Asphalte, owing to its impervious nature, is an effective damp-proof course, and is easily applied in any position; for these reasons it is largely employed. It has one defect, however, viz., its liability to squeeze out under heavy buildings in hot climates; but for temperate climates there is no danger of this occurring, and under all ordinary conditions it is probably superior to all other materials.

Basement stories constructed in water-logged soils may be rendered dry by treating it as a tank lined with asphalte, the latter being applied in existing buildings by constructing a 4½ inch wall, ¾ inch distant from the existing wall, and

the joints of which have been raked out, and filling the space between the two walls with asphalte in a heated and liquid condition. In constructing the $4\frac{1}{2}$ inch wall, three courses at a time should be built, a board the thickness of the cavity being kept between the two walls to keep the space clear; the back joint of the $4\frac{1}{2}$ inch wall must also be kept back for about 1 inch. When the three courses are erected the board is withdrawn, and the asphalte is poured into the space left between the walls. This method of obtaining a key and binding the two walls together is sufficient to render the $4\frac{1}{2}$ inch wall stable enough in most cases to resist the pressure of water from the outside.

In the method known as Callender's Bitumen Damp Course, the material is placed in sheets against the old wall, in which a half brick is taken out in every square yard of its face; into this a bitumen pocket is fitted, the edges of which lap over the face sheets. The $4\frac{1}{2}$ inch wall is then built up against the latter, the pockets making it possible to form a tie by using 9 inch heads through the $4\frac{1}{2}$ inch wall, as shown in Figure 47.

The water may be prevented from passing through the floor by laying asphalte on the 6 inch concrete covering the site. This must be weighed down by bricks on edge or 6 inch concrete over the whole area. In spaces where the span between the walls is great, the upward pressure may be resisted by forming a concrete invert, as shown in Figure 48, and bedding a one-ring inverted arch between the walls, and filling up to a level with concrete, or by omitting the arch and filling up to the level with concrete, as shown in Figure 48, or by laying the asphalte level and bedding steel joists of sufficient section to resist the upward pressure and embedding in concrete.

Hollow or Cavity Walls.—Hollow walls are used for two purposes: 1st, to prevent the loss of heat by conduction,

and preserve a more equable temperature in the interior of buildings; 2ndly, to prevent dampness passing from the exterior to the interior of a building.

Hollow walls are constructed by building two walls, one usually half a brick in thickness (this being placed on the outside of the building); the second is made of sufficient thickness to support the floors, roofs, etc., and is placed on the inside in order that the span of the floors or girders shall not be increased; and to comply with the Model Bye-laws, the aggregate thickness of the two parts must equal the minimum prescribed thicknesses of walls, similar dimensions and class. The space between the walls is usually $2\frac{1}{4}$ inches in width, and to comply with the Model Bye-laws, must not exceed 3 inches, the two walls being connected by iron ties, or special stoneware bonding bricks. If the ties are of iron, they should be twisted, or have a dip in the centre, as shown in Figure 153, to prevent any moisture that penetrates the thin outside wall being conducted across the iron ties to the thick wall. The glazed stoneware bricks are bent, as shown in Figure 153, so that the back end bonds into the inside wall one course higher than the remaining end bonds into the front wall; this is also to prevent moisture being conducted from back to front by means of the tie. Where iron ties are employed, they should be either galvanized or tarred and sanded, to preserve them from oxidation. There should be at least one tie in every 3 feet lineal, and one in every 1 foot 6 inches in height; they should not be placed one directly over the other, but midway between those in the row directly beneath them.

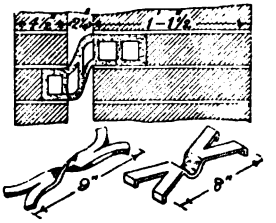


Fig. 153.

Where hollow walls are employed in stone-fronted buildings, the thin wall is built on the inside owing to the difficulty and expense in constructing thin walls in stone; where this occurs, a space is left in the thin walls about all girders where they penetrate them, so as not to receive any of the weight from the girders.

The tops of all windows and door frames should be covered with sheet lead to preserve them from any moisture that may drain upon them (as shown in Figure 154), and the lead should extend nine inches beyond the ends of the woodwork, in order to throw all water clear of it.

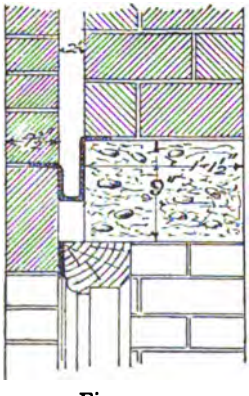


Fig. 154.

The cavity between the walls should extend from the top of the damp-proof course at the base, over the whole surface of the walls, to a height above the level of the highest ceiling; and should in all cases be protected at this part with a damp-proof course, to prevent any moisture descending from the top.

The cavity is sometimes continued below the ground level, but this is not good, as this part is liable to become filled with water that has percolated through the thin front wall from the adjacent earth, and where the space is constructed thus, it should be filled with some impervious material to the level of the damp-proof course above the ground.

A class of hollow wall, termed dry areas, is often employed at the portion of the bases of walls below the ground level. They consist of a small retaining wall, situated about 6 inches and upwards from the outside of the main wall, and serve to support the surrounding earth,

and prevent the latter from coming into contact with the main wall; wherever they are used provision must be made to drain them, or water will accumulate and dampness ensue.

Dry areas are necessary where basements exist, either wholly or partly below the ground level. Where the basement floor level is much below the ground, these retaining walls if built straight would have to be of great thickness; but the thickness may be greatly lessened if the walls are made segmental in plan, abutting against the main walls at intervals, thus forming a number of horizontal arches.

Dry areas and hollow walls, although answering admirably for the purposes for which they were designed, are not sanitary, and are being rapidly superseded by building with thick walls, which answer the same purposes effectively, and do not possess their disadvantages.

The small cavity, which it is impossible at any time to clear, forms a convenient run and harbourage for all kinds of vermin that infest houses, and these when dead, together with any matter they may have carried there, on decomposition are prolific of bad odours.

A sufficient distance should be left between the walls of dry areas to allow of a man getting in and clearing them out; and, if possible, they should be left open at the top, and thus exposed to the effects of the air and light; where this cannot be done, they should be rejected, and another method be adopted, notably a vertical coating of asphalte, laid on the face of the wall, between the latter and the earth.

Plinth.—A horizontal and usually projecting course built at the bases of walls, as in Figure 157, to protect walls from injury and give additional strength.

String Course.—The name given to horizontal courses, sometimes projecting and moulded, built in the faces of walls, anywhere between the plinth and cornice, as in

Figure 156, to act as a tie, and architecturally to emphasize the horizontal divisions of a building.

Copings.—Coverings of walls constructed in brick or stone set in cement to form waterproof tops to prevent rain percolating into the interior of walls. Five sections are shown in Figure 155.

Corbelling.—It is sometimes considered expedient to support loads by the method of brick corbelling, which consists of one or more courses projecting the required distance from the wall.

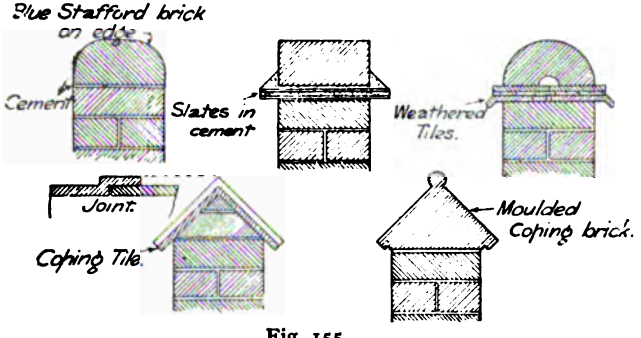


Fig. 155

There are two points that have to be considered in corbelling. The first is, that as every projecting brick is acting as a cantilever the end of the brick should be tailed into the wall as far as possible. To obtain this, as many headers as are available are used. Secondly, the projection of every course over the one below should not exceed $2\frac{1}{4}$ inches; but it is better if it is only $1\frac{1}{8}$ inch. Corbelling renders the walls less stable by bringing the centre of gravity of the mass nearer the internal edge of the wall. Figures 156 and 157 give two examples.

Brick Cornices.—Brick cornices are carried out on the principles of corbelling, the length of bricks being 9

inches. No cornice made entirely of bricks should project more than that amount. This being accepted, bricks are not suitable for the large projecting cornices of buildings treated in the Classic styles. Wherever bricks are employed in the latter styles, if the cornice has modillions, the latter are usually of stone of a colour resembling the bricks and well tailed into the wall, thus forming a support for the crowning courses as shown in Figure 164. Figure 163 shows the brick backing for a plastered cornice; the large projection is also here obtained by the use of stone. Bricks are more suitable for cornices of buildings of the

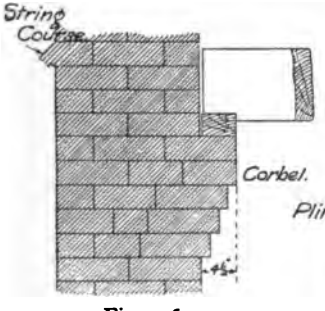


Fig. 156.

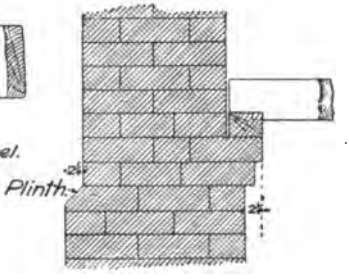


Fig. 157.

Gothic styles, which usually resolve themselves into a moulded band supported by a corbel table as shown in Figures 158 to 162. In either variety there is no detriment in placing the bricks on edge wherever the dimensions of the members or disposition of the parts render that arrangement necessary.

Fixing Joinery to Brickwork.—The following materials are generally built in or inserted into brickwork to assist in the fixing of joinery thereto :—

Breeze Bricks.—These are frequently built into the jambs of openings and other parts of walls to which joinery is to

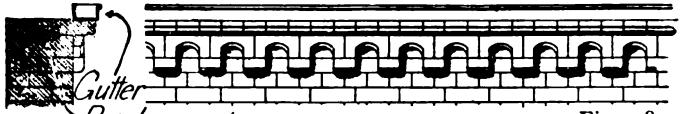


Fig. 158.

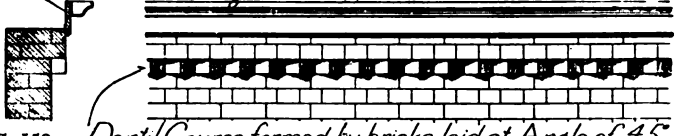


Fig. 159.

Fig. 160.

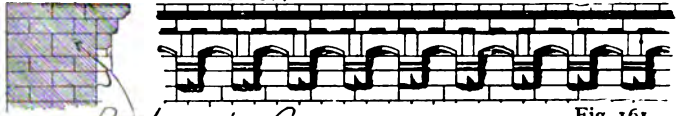


Fig. 161.

Fig. 162.

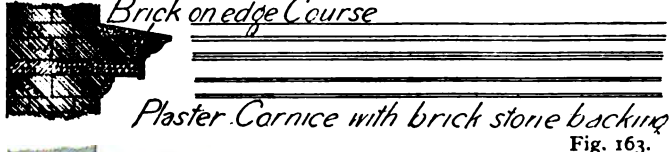


Fig. 163.

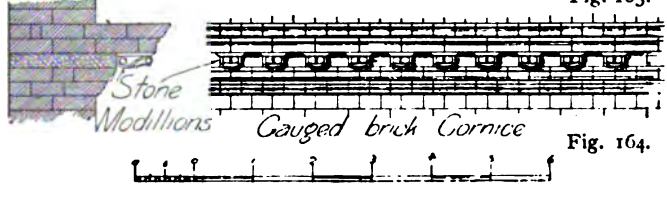


Fig. 164.

be fixed for securing the backings, as the bricks admit of nails and screws being driven into them and holding with tenacity.

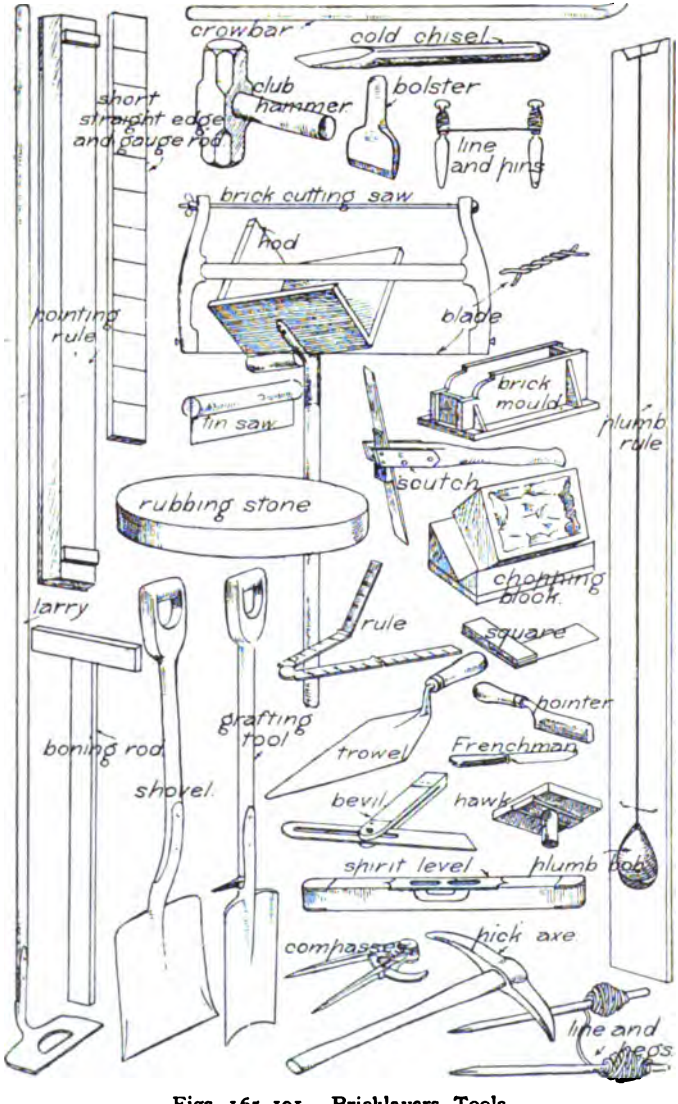
They have the advantage of not shrinking or perishing to the same extent as wood, but are inferior to wood in that nailed backings cannot be adjusted after having once been fixed. They are made of a similar thickness and width to ordinary bricks, and can be built in the walls in a similar manner.

Wood Bricks.—These are made of similar dimensions to ordinary bricks. They have been used to form fixing surfaces in brickwork, but they are objectionable because they shrink, become loose and are liable to rot.

Wood Plugs are wedges cut on the twist. They are usually driven between the joints of brickwork to obtain a fixing for joiners' work, but are not to be recommended in jambs or edges of walls, as they are very likely to damage such parts.

Wood Joints.—These are lengths of wood, $4\frac{1}{2}$ inches by $\frac{3}{8}$ inch, built into walls at intervals, or wherever fixing is required. The wood practically does not shrink in thickness; it is the best mode of fixing in most situations, but has to be inserted while the brickwork is being carried up.

Excavators' and Labourers' Tools.—The following tools as shown in Figures 165 to 194 are used by the excavator and labourer: 1, the pick for breaking up hard ground; 2, the grafting-tool for digging out earth such as stiff clay; 3, the shovel for lifting earth; 4, the line and pegs, for outlining trenches; 5, the boning rods for levelling; 6, the level, which consists of a spirit-level mounted in a straight-edge at least 10 feet in length; 7, the hod, this consists of three sides of a rectangular box mounted on a staff, and used for carrying bricks and mortar, and capable of carrying 12 bricks, or about $\frac{2}{3}$ of a bushel of mortar; 8, the larry, which is a steel blade bent at right angles, and fixed to a



Figs. 165–191. Bricklayers Tools

long handle and used for the mixing of mortar; 9, the beedle is a large wood mallet with a circular pine head, with rounded ends about 18 inches and 15 inches in diameter, with a handle about 3 feet long. It is used by the pavior for punning paving stones into their position when bedding, as shown in Figure 192; 10, the rammers

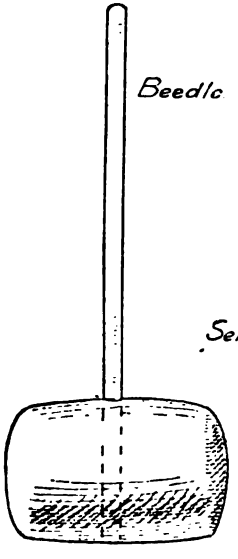


Fig. 192.

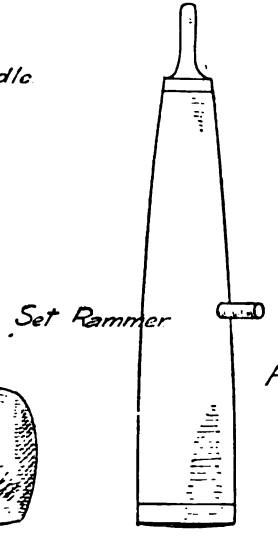


Fig. 193.

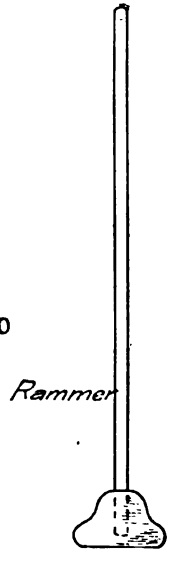


Fig. 194.

are of two kinds—1st, that used for ramming granite sets in roadways, and consists of a cylindrical piece of wood about 3 feet 6 inches long, with a vertical handle at top and a horizontal handle about half-way up, as shown in Figure 193; 2nd, that used for the bottoms of trenches and for consolidating ground. They are of the shape shown in Figure 194, the head being of iron and about 10 lbs. in weight; the handle is of ash about 10 feet long.

Bricklayers' Tools.—These may be described under the following heads, 1, setting out tools; 2, cutting tools; 3, laying tools; and 4, pointing tools. The setting out tools include the 2-foot rule for taking small measurements, and the 10-foot rod for the setting out of buildings, the 66-foot metallic woven tape also used for the same purpose; more accurate work, however, can be done with the rigid wooden rod than with the flexible tape. The large wood square for setting out right-angles; templets for setting out work curved or shaped in plan; the plumb-bob and rule for testing the verticality of work; the straight-edge usually three or four feet in length for trying the accuracy of plane surfaces; the pocket spirit-level usually employed with the short straight-edge for testing the horizontality of points not far apart; the long spirit-level with a stock about 10 feet in length for determining the horizontality of points great distances apart; the telescopic or surveyor's level for a similar purpose to the preceding tool; the level of points a great distance apart may be more accurately and expeditiously compared by means of this instrument than with the long level. Lines and pins for the building of straight lengths of walls between given corners; the square with a steel blade and wood stock and the bevil for marking bricks to be cut; the compasses for the division of lengths; the radius-rod for describing segments of large circles, and a large drawing-board for the setting out of arches or shaped work.

Brick-Cutting Tools.—Rough cutting: 1, the large trowel; 2, the club hammer and bolster, for cutting with greater exactitude than with the trowel; 3, the cold chisel for the cutting of chases and for general work.

Fair cutting, *Hard Bricks:* 1, the tin saw for making an incision $\frac{1}{8}$ of an inch deep, preparatory to cutting with bolster; 2, the chopping-block, which is an arrangement of two blocks of wood so fixed as to support a brick in an

angular position convenient for cutting; 3, the scutch consists of a stock and a blade, the latter generally formed of a flat file about 10 by 1 inches, sharpened at both ends and fixed in the stock by means of a wedge. This displaces, and is an improvement on the old brick-axe, as the blade can be removed and sharpened readily; it is used to hack away the rough portions on the side of a brick after the edges have been cut by the tin saw and bolster.

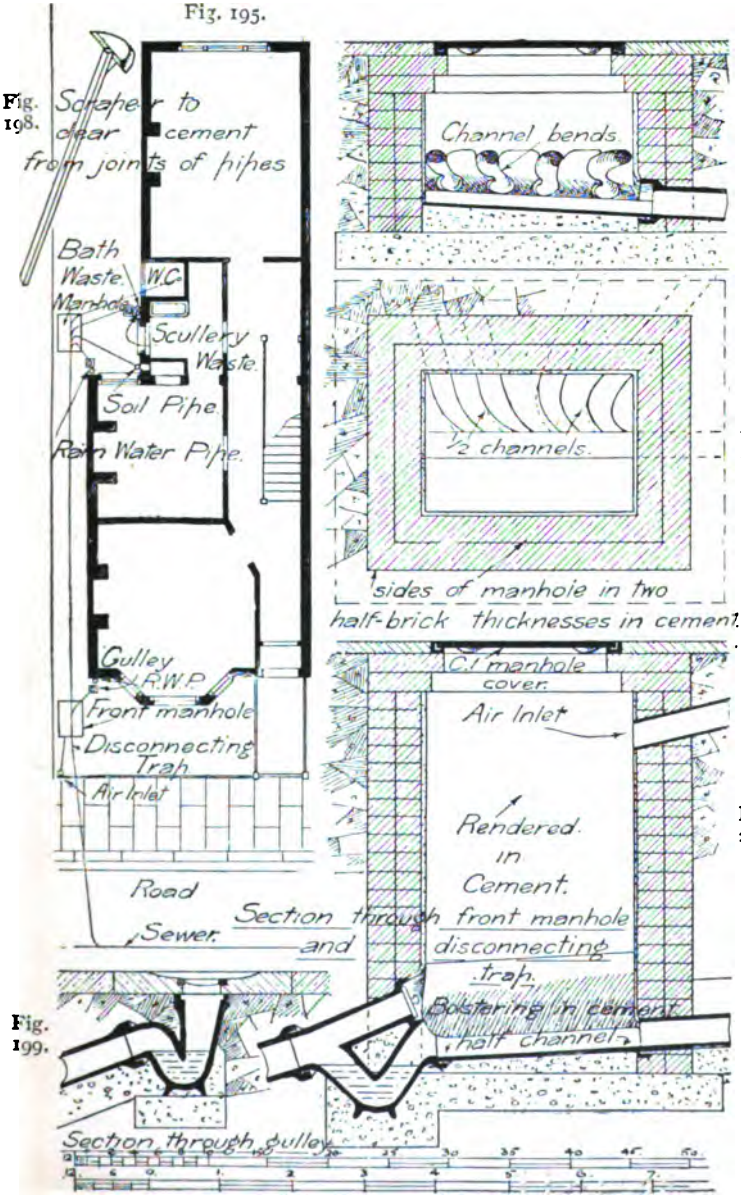
Fair cutting, *Soft Bricks:* 1, the saw, consists of a frame holding the blade, which consists of twisted soft steel or malleable iron wire, No. 18 B.W.G., and is used for cutting soft rubbing bricks; 2, the rubbing-stone, is a circular slab of gritty York stone 20 inches diameter, for rubbing the faces of bricks to a true surface; a few hand stones for finishing small surfaces and a few long files, parallel, flat and round, and a few rifflers for working returned and stopped mouldings; a surface plate of slate, as shown in Figure 589, for testing the accuracy of surfaces and the correct adjustment of the joints of contiguous blocks; 3, the mould is a wood box enclosing bricks that are to be cut to a shape, the sides of the box being formed to that shape, and the edge over which the saw-blade works is protected by a strip of zinc. A few pieces of thin sheet steel for working moulded circular work.

Laying and Pointing Tools.—1, the large trowel for the spreading of mortar when laying bricks; 2, small trowels for filling up joints of new brickwork; 3, the pointing rule, which is a feather-edged straight-edge, with two small pieces $\frac{3}{8}$ inch thick nailed at each end to keep the rule away from the wall and allow the trimmings to fall through; 4, the frenchman for trimming joints consists usually of an old table-knife, with the end ground and turned up, as shown in plate containing Figures 165 to 191; 5, the jointer, used for tuck pointing in old work.

CHAPTER III.

DRAINS.

House Drains.—The sewage and refuse fluid matter of domestic buildings is conveyed from water-closets, baths, sinks, etc., by means of pipes to a cesspool or to a sewer. It is desirable to remove this matter as quickly as possible, before putrefaction takes place, and in such a manner that all objectionable odours are reduced to a minimum and so that any adjacent soil is not contaminated. Impervious stoneware, or cast-iron, pipes, and good water-sealed traps are used. It is desirable that all runs of pipes should be laid straight and an inspection chamber constructed at each horizontal angle or bend to permit of easy access in case of any stoppage of the drain. The various branch drains of the sanitary system of a building should as far as possible be collected at a manhole, as shown in Figure 195, and not joined to any other part of the underground system. Between the house drains and the sewer, or the cesspool, into which the drain discharges there should be a disconnecting trap, as shown in Figure 200, with an effective water seal to prevent the escape of any drain air or gases. All soil pipes should be taken to drains leading direct to a manhole without any intervening traps, and their upper ends should be continued above the highest window in the house, in order that they may serve as ventilators to the drains on the house side of the disconnecting traps. All waste pipes should discharge over or



Figs. 195–200. House Drains.

into open trapped gullies in order that all such pipes may be flushed with air other than that from the drain. The laying of the drains, if of stoneware, is usually executed by the bricklayer. The following would be the method adopted for a small terrace house, as shown on plan Figure 195. All other systems would be laid on similar principles but modified to comply with any peculiar conditions.

In the case of a terrace house, the drains should be laid after the building has been erected and the ground has had time to settle.

The line of drains should be set out, the trenches cut to the true gradients, and the earth for the manholes removed, the bottoms of the trenches and the manholes are then covered with 6 inches of good concrete. The disconnecting trap should then be embedded in concrete in the lower manhole and connected with a drain leading to the sewage system. The invert channels in the lower manhole should then be bedded, and the straight portion of pipe between the two manholes laid and connected with the channels in the respective manholes. The various branch channel connections are then made, and drains laid to receive the waste water from sinks, baths, and rain water pipes through a gully trap. Such trap disconnects the drain from the outer air. Branch drains connected with soil pipes are not trapped, but the soil pipe is continued upwards as before stated to act as a vent. The manholes are then built, the walls of which are 9 inches thick and built in two separate half-brick thicknesses in cement mortar to render them less likely to leak. By having no "through" joints, excepting those for bedding the bricks, the manholes are not so likely to leak when a water test is applied. The spaces between the channels and walls are benched to a height of at least 6 inches and rendered in cement with a trowelled surface. The sides of the manhole should also be rendered in cement. After the cement has thoroughly set the drains should be

tested, and, if found to be satisfactory, they should be backed up with concrete to half their height; or, if the pipes are laid under a house, they should be completely enveloped in concrete all round the pipe for a thickness of 6 inches. The ground may then be filled in and lightly punned.

Many stoneware pipes are slightly curved in their length. Any pipes deviating from straightness should be so arranged as to lie in a horizontal plane, and thus avoid an irregular gradient in the invert of the drain.

The pipes are usually jointed in neat cement, which should be properly cooled, before wetting, but not "killed," or further mixed up after the initial setting has commenced, and then used. Before bedding the pipe, the socket of the last laid pipe should have a layer of cement bedded in it; the spigot end of the next pipe is then inserted, and care taken to pack it perfectly concentric with the preceding pipe. Neat cement should then be tucked in and pressed home in the socket with a piece of wood cut for that purpose, and thus ensure the joint being quite solid. The joint is then flushed up with cement. On inserting the pipe a large amount of the cement first bedded will be squeezed into the interior of the pipe; this surplus cement should be carefully scraped out, each time a joint is made, with the tool shown in Figure 198, to prevent any projections on the inside of the pipe.

A better method of procedure, where straight lengths of drains occur as between two manholes, is as follows:—On the prepared bed of concrete lay all the pipes in each length or run and with a crowbar, or prize, force all the spigot ends of the pipes into the sockets and hard up against the socket shoulders. Then commence at the lower end and bed the first pipe on the concrete, then lay the second pipe and ensure that it is concentric with the first pipe by packing it at the sides with concrete. In a similar manner centre and bed all the remainder of the pipes. Ample

clearance about the pipes should be left for the making of the cement joints. Then return to the lower end and commence to make the joints, using only cement. Care should be taken to force the cement well into the joints; ram it in with a wood tool specially made for this purpose. Finally flush the joint level with the face of the socket. Most workmen leave an external fillet of cement, but this is unnecessary. The advantage claimed for this method is that the joints can be made without causing the slightest movements in the pipes. After testing the pipes they are enclosed with concrete as prescribed by the Bye-laws.

Drain Testing.—There are three methods of testing the soundness of drains and fittings—viz., by (1) essences or volatile oils, (2) smoke, (3) hydraulic pressure, (4) air pressure.

1. Defects may be discovered by carefully pouring volatile oil, such as strong essence of peppermint, followed by hot water, down the highest part of the drainage system. If the odour of the oil escapes, the existence of a defect is proved. This test, however, is not reliable, as a defect may not be discovered by its application.

2. The second test consists in charging the drains with smoke by means of a smoke rocket or a smoke machine. This test can be applied through the fresh-air inlet to the drains, or through the ventilating pipe, or through a gully trap from which the water has been removed. An escape of smoke at any part would indicate a defect.

3. The hydraulic pressure test consists in stopping up the drain where it enters the disconnecting chamber by means of an inflated india-rubber bag, or by an india-rubber plug, and then filling the whole of the drainage system with water until it rises to the level of a surface gully or another manhole. If after a time, say half an hour, the water is found to subside, this would denote a leakage. This test is the only reliable one for drains, and is usually applied

to drains when laid underground. For the vertical parts of a drainage system, such as the soil pipes, etc., the smoke tests, the pressure of which is only equal to about $\frac{1}{2}$ inch of water, is used and considered sufficient. All pipes should be subjected to the hydraulic and smoke test before being covered in and on completion of the works.

4. The air pressure test as applied to drains consists of plugging the soil pipes, or drain ventilating drains if any, then examining if all manhole covers are properly fitted and all traps are properly sealed with water. Air is then forced into the drains by means of a pump similar to a large size bicycle pump. A glass syphon pressure gauge filled with water is necessary to show the air pressure exerted in the drains. Under ordinary conditions an air pressure of 1·5 inches can be exerted. If a test under a greater pressure than 1·5 inches is desired it becomes necessary to plug all the gully and water closet traps in addition to the main drain trap in the disconnecting manhole. The syphon pressure gauge should be of a depth in proportion to the air pressure to be resisted.

Stoneware Drains.—The following is an excerpt from the London County Council Bye-laws under the Metropolis Management Act, 1855 :—

Thickness, sockets and joints of stoneware pipes.

"If he shall construct any such drain of stoneware or material other than metal, the thickness of the pipes, and depths of the sockets, and the annular space for the cement in proportion to the diameter shall be as follows :

Internal diameter. Inches.	Thickness of pipe, not less than—	Depth of socket, not less than, inches—	Annular space for the cement, not less than—
3	$\frac{1}{2}$ of an inch	$1\frac{1}{2}$	$\frac{5}{16}$ of an inch
4	$\frac{5}{8}$ "	$1\frac{3}{4}$	$\frac{5}{16}$ "
5	$\frac{5}{8}$ "	2	$\frac{5}{16}$ "
6	$\frac{5}{8}$ "	2	$\frac{5}{16}$ "
9	$\frac{3}{4}$ "	2	$\frac{7}{16}$ "

Drains under buildings.

"Where any such drain (other than a drain constructed for the drainage of the subsoil of the site of a building) passes under a building, he shall cause such part thereof as passes under the building to be laid where practicable in a direct line for the whole distance beneath such building, and to be completely embedded in and covered with good and solid concrete at least six inches thick all round."

Brick Drains.—These are large conduits for sewage, rain, and waste water, and are employed where the sectional area required is greater than can be obtained by using stoneware pipes, *i.e.*, about 2 feet diameter. They are made of various sections, the two most generally used being the circular and the egg-shaped.

Circular Drains are usually constructed of at least two half-brick rings set in cement on a concrete foundation formed round a centre. On the concrete bed the invert of the arch is laid, the upper part of the drain being built in the usual way as an arch with a centre support.

Concrete drains, as shown in Figure 203, are made by Messrs. Sharp, Jones & Co., of Dorsetshire. They are efficient and economical, and are now largely used, from 15 inches diameter and upwards, as surface and foul water drains. The concrete sections are laid and then jointed with neat cement.

Egg-shaped Sewers.—These are employed to increase the velocity of the flow by making the current deeper. The advantage of this shape over the circular is most apparent when there is only a small quantity of water in the drain. The method of striking the curves for framing the wood centres is shown by Figure 201. The construction is as follows:—a bed of concrete, with a horizontal surface levelled to the proper falls, is laid in the trench; on this the invert is bedded, this being made of blue Staffordshire bricks, vitrified stoneware, or terra-cotta, as shown in Figure 202. Concrete is then shot in behind a centre to the height of the invert; the bricks to the latter point are

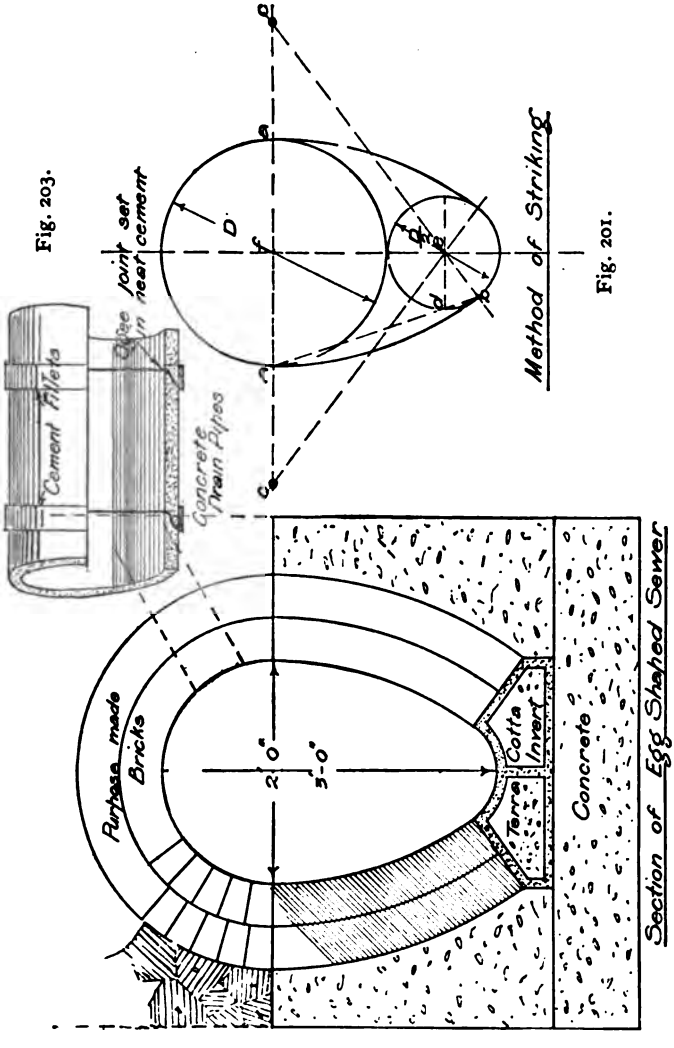


Fig. 203.

Fig. 201.

Fig. 202.

Fig. 205.

Fig. 204.

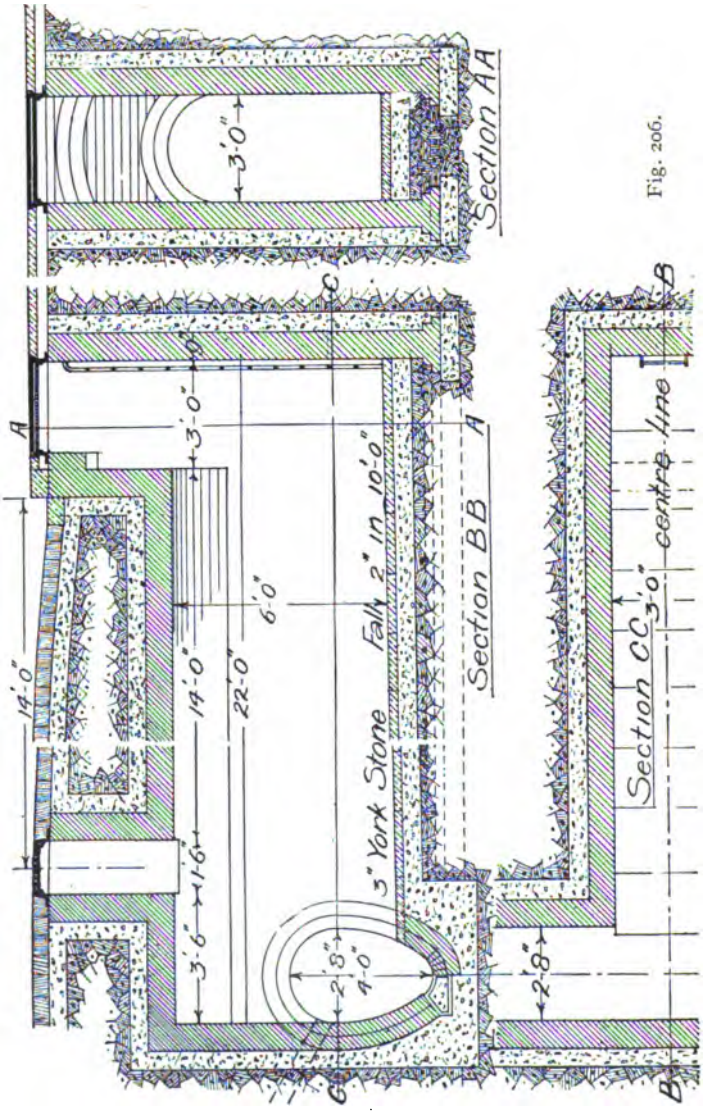


Fig. 206.

now laid generally in two half-brick rings, the sides backed up with concrete, and the upper part is then arched and the earth filled in. Any connections that are made to the sewer from the house drains should be taken through the side just beneath the spring of the covering arch, which is the highest point to which water would rise under ordinary conditions. All house drains should have an iron flap trap on the outlet end to prevent any back flow should the sewer become filled or the water line rise above the normal, as it often does after heavy rains. These flap traps also help to prevent any vermin entering the house drains from the sewer. Sewers are usually built of ordinary-shaped bricks, which leave a large wedge-shaped joint; to avoid this defect especially shaped bricks are now largely employed.

The outline for oval or egg-shaped sewers, as shown in Figure 201, may be found as follows:—let two-thirds of the required depth be taken as D, the diameter of the circle f; describe another circle around the centre e, with diameter $\frac{D}{2}$ tangent to D; join by a straight line centres f and e, and draw perpendiculars to this line passing through f and e, and produce these lines intersecting circles in a and d; join a and d by a straight line, and produce till it cuts circle e at b; join b and e by a straight line and produce till it cuts a f produced in c; then, because the triangles e d b and c a b are similar, c is the centre of a circle tangent to circles f and e at the points a and b respectively.—(Q.E.D.)

Figures 204 to 206 show three views illustrating sections of sewer, side-inlet manhole, and ventilating shaft in the centre of the roadway.

Fall for Drains.—The drains should be laid with a fall sufficient to give a velocity to effectually scour away all heavy matters and yet not too rapid to leave stranded fæcal matter behind. With too high a velocity of flow, especially

in sewers into which grit and gravel enters in considerable quantities, the invert is eroded by the friction of what passes over it. Hence the evils of having too high a velocity of flow. The velocity according to Parkes should be from $2\frac{1}{2}$ to 4 feet per second when flowing either half or full bore. The best formula for general use is Neville's, viz. :—

$$v = 140 \sqrt{RS} - 11 \sqrt[3]{RS}$$

when

v = velocity in feet per second
R = hydraulic mean depth, that is the sectional area of the fluid divided by wetted perimeter; this will equal when flowing half or full bore, diameter of pipe divided by four
S = sine of the inclination of the pipes.

Then to determine the velocity of 4-inch pipes laid to a fall of 1 in 40, and running half or full bore :—

$$v = 140 \sqrt{RS} - 11 \sqrt[3]{RS}$$
$$v = 140 \sqrt{\tfrac{d}{4} \tfrac{1}{40}} - 11 \sqrt[3]{\tfrac{d}{4} \tfrac{1}{40}}$$
$$v = 140 \sqrt{\tfrac{1}{160}} - 11 \sqrt[3]{\tfrac{1}{160}}$$
$$v = 6{\cdot}39 - 1{\cdot}4$$
$$v = 4{\cdot}99 \text{ feet per second.}$$

This is only slightly in excess of the desired velocity, but as drains in ordinary use rarely run more than one-quarter bore this inclination of 1 in 40 for 4-inch drains will be found to be within the required limits of velocity, *i.e.*, from $2\frac{1}{2}$ to 4 feet per second. Let it be required to determine the velocity of 4-inch pipes laid to a fall of 1 in 40 and running one quarter bore.

$$v = 140 \sqrt{RS} - 11 \sqrt[3]{RS}$$
$$= 140 \sqrt{{\cdot}045968 \times \tfrac{1}{40}} - 11 \sqrt{{\cdot}045968 \times \tfrac{1}{40}}$$
$$= 4{\cdot}75 - 1{\cdot}15$$
$$= 3{\cdot}6 \text{ feet per second.}$$

The most useful falls for the following sizes of drains are :—

Diameter of pipe.	Sine of inclination.
4″	1 in 40
6″	1 in 60
9″	1 in 90
12″	1 in 120

It should be noted that drains of the above sizes and laid to the given inclination when flowing half or full bore all have approximately the same velocity.

CHAPTER IV.

PAVING.

Paving.—External areas in towns, or about houses where not required for garden purposes, are usually covered with some form of stone or brick to give a hard surface to walk upon and to facilitate drainage. The following materials and methods are employed:—brick, stone or concrete slabs, concrete slabs formed *in situ*, tar paving, asphalting, tiling and mosaic. Bricks for paving should be hard, well burnt and wear with a rough surface. Specially hard bricks, chequered on surface to afford a firm foothold, are manufactured for use in stables and similar positions. Bricks may be laid flat or on edge. Where laid flat, the area is usually covered with 6 inches of concrete, the bricks being then bedded on this in lime or cement mortar; where laid on edge, the ground is either concreted as before, or the surface of earth is levelled and the bricks are bedded in sand, the side joints of the bricks being then filled up with lime or cement grouting.

Stone or Concrete Slabs.—Slabs of highly stratified stone that can be easily rent into approximately uniform thicknesses, tooled on surface, squared on edges, are largely used for paving. The method of laying is as follows:—The ground is first levelled, and the surface covered with sand or sifted earth; the stones are then laid, being bedded in lime mortar about their edges. They are punned to their requisite levels with a tool known as a beedle, which also

consolidates them upon their bed. Figure 6 illustrates the laying of stone paving. Concrete slabs have of late years been largely used for paving; they have the advantage of being cast in uniform superficial dimensions and thicknesses, which presents a uniformity in the appearance of the joints upon completion, and greatly enhances the appearance. To obtain a similar effect in stone would be expensive, due to the waste in cutting.

Concrete Paving in Situ.—This method is largely adopted, in preference to the slab method, on account of the uniformity of the pavement and the fewness of the joints, which renders them clean and sanitary. Before the paving is applied, the earth is levelled and a bottoming of at least 6 inches in thickness is formed of large flat stones or bricks laid at random. The concrete is then laid, being usually formed in sections about 6 feet square and 3 inches in thickness, and finished with about $\frac{3}{4}$ inch of fine stuff floated to the correct levels. While the surface is still soft, a metal roller is passed over it, producing a chequered face. The disadvantage of forming large concrete pavements is, that if any part settles and cracks the fracture is likely to star and spread in all directions. This effect is minimised by the formation of sheets not larger than 6 feet square, any damage being localised within this area.

Tar Paving.—This is prepared of the following materials and in the proportions of 12 gallons of coal tar, $\frac{1}{2}$ cwt. of pitch, 2 gallons of creosote oil, and one ton of screened mountain limestone or Kentish rag, broken and screened to pass through meshes of $1\frac{1}{2}$, $\frac{3}{4}$ and $\frac{1}{2}$ inch mesh. The tar, pitch, and creosote are brought to a boiling condition, and the stone, which has been previously dried by heating, is added. It is deposited in three layers—the bottom layer, with the coarse aggregate, being equal to one-half the total thickness; the second and the final layers, with the medium and fine aggregates respectively, are each laid to one-fourth

of the total thickness. The compound is spread over the site by means of an iron rake; finely divided limestone, sand or grit is thrown over the top and finished by being well rolled to an even surface.

The total thickness of tar paving by this method varies from $2\frac{1}{2}$ to 4 inches. Another method is to lay a coat of tar paving $1\frac{1}{2}$ inch thick, composed of fine particles, upon a prepared surface of concrete 6 inches thick.

Asphalte Paving.—The various methods of asphalte paving are fully dealt with in the chapter on "Materials."

Tile Paving.—These are thin slabs of finely-prepared and well-burnt clay. They are manufactured in various colours and shapes up to about 12 inches square. The area to be tiled is covered with a bed of 6 inches of concrete; it is then floated with a coat about $\frac{3}{4}$ inch thick, composed of one of cement and one of sand screeded to an even surface. The tiles are then placed in position and pressed into the cement bed, the latter oozing up between the side joints.

Mosaic Paving.—There are two varieties of mosaic paving, Roman and Venetian. In both it is necessary to have a prepared ground of 6 inches of good concrete, on which a coat of $\frac{3}{4}$ inch of neat cement is floated.

The Roman variety consists of pressing into this floating coat small approximate cubes of marble of different colours about $\frac{3}{4}$ inch length of side. These may be arranged in various patterns. Pictorial designs are frequently worked. The design is first worked and coloured on paper, the stones required are selected, fitted and stuck on to the drawing, the whole pattern is then placed in position, stones lowermost on the prepared bed of cement. When the cement floating coat has set, the paper is damped and removed; the small cubes forming the ground colours are then bedded singly up to the design, when the whole surface is covered, the face is levelled and polished by rubbing with a stone.

The Venetian variety is carried out by sprinkling small

irregularly shaped chips of marble on to the floating coat of cement previously described; these are pressed into the surface with a hand float, and the whole is consolidated by rolling with a heavy iron roller. Patterns in various designs may be formed in this method by first cutting out the design in wood, and bedding the pieces of the latter in position The ground work is then bedded about the patterns, and. when set, the wood patterns are removed and the voids filled with cement coloured with pigments, and with chips of different coloured marbles pressed in as described. The whole is then levelled and polished as in the Roman variety.

In floors composed of steel and concrete the rigid surface formed by the mosaic is subject to cracking, owing to the expansion and contraction of the joists. The ill effect of this is minimised by arranging the floor in sections, so that border lines, and consequently natural joints, are formed along the lines in which the variable expansion takes place. It is not advisable to make any dimension of these sections greater than 10 feet.

CHAPTER V.

MASONRY.

Definition.—Masonry is the art of building in stone in a similar manner to that of brick, with the exception that brickwork is carried out with uniform-sized blocks, thus admitting of a number of definite systems of laying the bricks; whereas in stone, owing to the expense in working the material, the face stones only are squared, and the interior or hearting is filled up with smaller stones roughly fitted with a hammer. The stones are in the great majority of cases of varying dimensions, thereby making it a matter of great skill to obtain a proper bond in the work; and owing to the irregular shape of the material the walls have to be made considerably thicker than walls of the same height in brick, with the exception where the walls are built of coursed stones properly squared, in which case the thickness may be even less than that of brick walls.

The great dimensions in which stone may be obtained, lends itself to a much greater degree than bricks for buildings of architectural pretensions, rendering it possible to have cornices and corbelled work of great projection which is impossible in brickwork.

Technical Terms.—The following is a list, and also an explanation, of the terms used in stonework:—

Bond, Lap and Course.—These terms have the same meaning as given under brickwork.

Through Stones. — Stones which extend through the entire thickness of walls to tie or bond them. These are objectionable, as damp is more likely to show on the interior of walls where the continuity of the material is uninterrupted.

Headers.—The name applied to stones, the lengths of which are $\frac{2}{3}$ to $\frac{3}{4}$ thickness of the wall, laid transversely.

Bonders.—These may be either "throughs" or "headers."

Grout.—This is a thin mortar, which is poured over the stones when brought up to a level surface, to fill up any interstices between the stones in the hearting of walls or other positions as necessity requires.

Spalls or Shivers.—These are broken chips of stone, worked off in the dressing.

Weathering.—The top face of a stone worked to a plane surface inclined to the horizontal for the purpose of throwing off the water is said to be weathered, as in sills, cornices, etc.

Footings.—The object of footings is the same as in brick walls. Stone footings should be large rectangular through stone blocks. Square stones in plan are not so good as oblong. All stones in the same course must be of the same height, but all courses need not necessarily be of the same depth. The breadth of set-offs need not exceed 3 or 4 inches.

If the expense of stone is an objection, footings may be made of bricks or beds of concrete of sufficient depth. See chapters on Foundations and on Brickwork.

Bed Surface.—The bed surface must be worked in one plane surface. Masons to form thin joints often make the beds hollow. This is bad, as it is liable to spall; all the pressure will be thrown on the outer part, which is liable to spall the edge of the stone.

Galleting.—The term given when small pieces of flint or pebbles are pressed into the face joints of rubble walls to

preserve the mortar and to give a pleasing effect, as shown in Figure 247.

Dressings.—Stones are said to be dressed when their faces are brought to a fair surface; but cut or prepared stones used as finishings to quoins, window and door openings, as shown in Figure 444, are described as dressings.

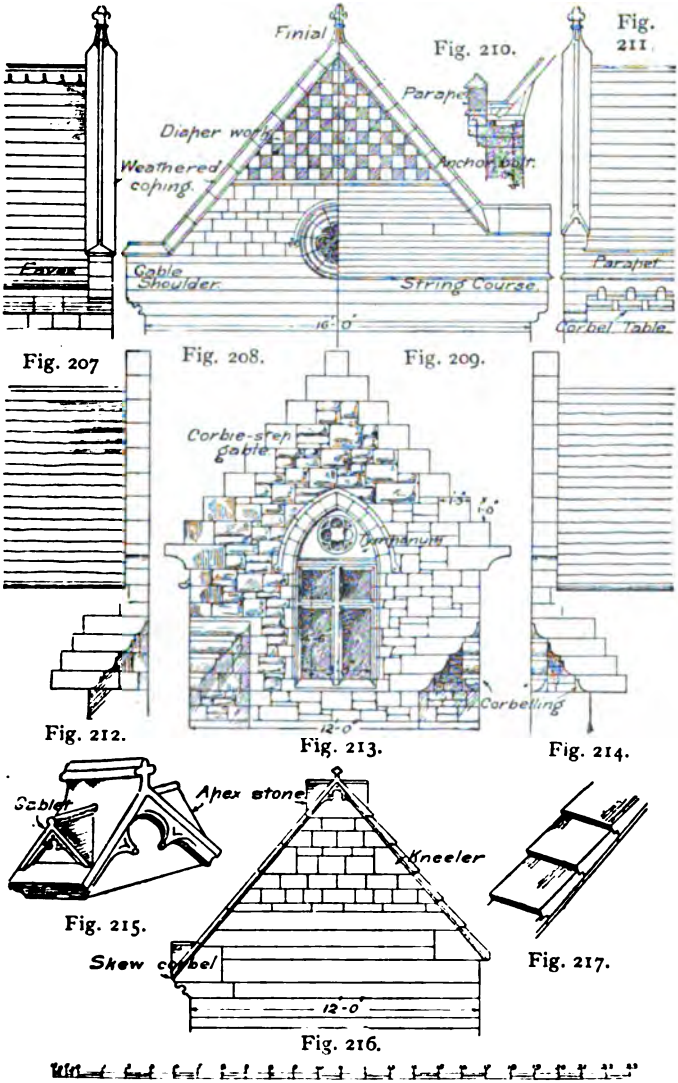
Quoins.—In rubble and inferior stone walls, quoins are built of good blocks of ashlar stone to give strength to the wall. These are sometimes worked to give a pleasing effect, and where hammer dressed and chamfered, as in Figure 260, are said to be rusticated. They are, at times, merely built with a rough or quarry face, as in elevation Figure 259, only having the four face edges of each stone lying in one plane.

Window and Door Jambs.—For purposes of strength these should be of cut stone, attention being given that each course is securely bonded. For that reason it would not be advisable to build them of rubble. Figures 444 to 449 show alternate courses, one showing the stones forming the window jambs acting as stretchers—these are termed outbands, as shown in Figure 449; and the other a through stone or header forming the face of reveal and the face of rebated jamb, and is termed an inband, as shown in Figure 445.

Scontions.—The stones forming the inside angle of the jamb of a door or window opening, as shown in Figure 458.

These are often cast in concrete to effect a saving in labour.

Sills—These are the lower horizontal members of openings; those in stone are usually of one length, being pinned in cement to both sides of the opening. They should be fixed after the carcase of a building has been finished, and any settlement that was likely to occur through a number of wet mortar joints has taken place. They may be plain and square, as for door sills, or sunk, weathered, moulded



Figs. 207–217. Finishings of Gables.

with drip and with properly formed stools, and grooved for metal water bar, or moulded, grooved and weathered, as shown in Figures 450 to 452.

Corbel.—A stone projecting from a wall to support a projecting feature. Figures 212 to 214 show methods of supporting a projecting angle of a building by means of corbels.

Skew Corbel.—As shown in Figure 216, is a projecting stone at the lowest part of the triangular portion of the gable end of a wall supporting the starting piece of coping, and resisting the sliding tendency of the latter. The skew corbels are often tied in to the wall by long iron cramps.

Kneeler or Skewput.—This is a long stone, tailing well into the gable wall, as shown in Figure 216, and resists the sliding tendency of the coping.

Saddle or Apex Stone.—The highest stone of a gable end cut to form the termination of two adjacent inclined surfaces as shown in Figures 215 and 216.

Lacing Course.—Owing to the absence of bond in flint walls, courses of bricks, three deep, are inserted at intervals, to give strength to the wall and bring it to a level surface, as shown in Figures 248 and 249. Sometimes the name is applied to a horizontal band of stone placed in rubble or flint walls to form a longitudinal tie.

String Courses.—Horizontal bands of stone, sometimes moulded and projecting, as in Figures 260 and 261, often carried below windows to accentuate the horizontal divisions of a building.

Plinth.—A horizontal projecting course or courses built at the base of a wall, as in Figures 260 and 261. These are to protect the wall, and are often built in hard hammer-dressed stones.

Cornices.—The moulded course of masonry crowning buildings, generally having a large projection, as shown in Figures 260 and 261, to throw off the rain.

Saddled or Water Joint.—To protect the joints of cornices and other exposed horizontal surfaces of masonry the sinking is sometimes stopped before the joint and weathered off, as shown in Figures 267 to 269. Any water passing down the weathered surface is guided away from the joint. The expense of this joint often prohibits its use.

Blocking Course.—A course of stones erected to make a termination to the cornice (see Figures 260 and 261), the object being to gain extra weight to tail down the cornice, and to form a parapet.

Copings.—The highest and covering course of masonry forming a waterproof top, to preserve the interior of wall from wet, which in frosty weather might burst the wall. Figure 216 shows a coping flat on the top surface, which should be used only for inclined surfaces, as on a gable, or in sheltered positions. Figures 245 and 246 give section and elevation of feather-edged copings, which throw water off on one side of walls, and are necessary for parapet walls of crowded thoroughfares. Saddle-back is the name applied when the upper surface is weathered both ways, as in Figures 253 and 256; and segmental, when the section of coping shows the upper surface to be a part of a circle, as in Figures 250 and 251.

Rebated Joints.—These joints are used for stone roofs and copings to obtain weather-tight joints. There are two kinds: (1) when both stones are rebated; (2) when the upper stone only is rebated. In the first case the stones are of the same thickness throughout, their upper surface being level when the joint is made. In the second case the stones are thicker at the bottom edges than at the top, the bottom edge having a rebate taken out equal to the thickness of the upper edge of the stone below it, over which it fits. The part that laps over should not be less than $\frac{3}{4}$ inch thick. The under surfaces or beds of the stones should be level, as shown in Figures 224 and 225.

Throatings.—Grooves on the under surfaces of copings, sills, string courses, etc., acting as drips for any water that would otherwise trickle down and disfigure the walls, as in section Figure 253.

Templates.—Slabs of stone placed under the end of a beam or girder to distribute the weight over a greater area.

Gable Details.—The tops of stone walls are protected by coping, and these, where placed on steep gables, need support at their lower ends and at intervals; this may be done by constructing a shoulder at the foot, as shown in Figures 208 and 209, or by the use of skew corbels as shown in Figure 216; the intermediate supports are obtained by kneelers, which consist of stones having a part worked as a coping, the remainder tailing well into the wall, as shown in Figure 216.

Corbie Step Gables.—A common method of finishing gables is by constructing a number of steps formed of some hard stone squared, the top surfaces being slightly weathered, as shown in Figures 212 to 214, known as corbie or crow-step gabling.

Gablets.—Many skew corbels are constructed with a small gablet as shown in Figure 215, which gives extra weight to the skew corbel, thus rendering it more efficient for resisting the outward thrust of the coping stones. The apex stones are often treated in a similar manner.

Corbel-table.—A system of corbelling supporting a parapet, often forming an architectural feature, as shown in Figure 211.

Finial.—The aspiring ornament of an apex stone, often richly foliated, as shown in Figures 207 to 209.

Parapet.—The fence wall in front of the gutter at the eaves of a roof, as shown in Figure 210. The castellated parapet is formed by a number of embrasures similar to the parapets used in ancient military buildings, as shown in

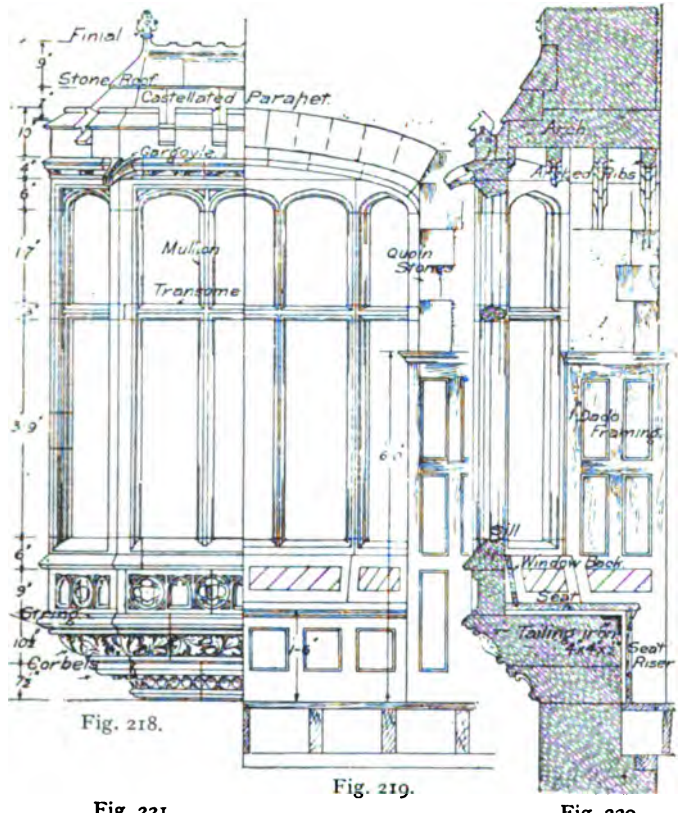
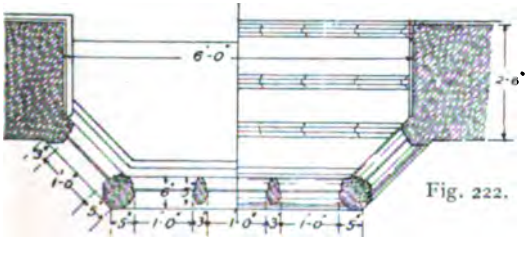


Fig. 221.



Figs. 218–222. Example of an Oriel Window.

Figure 218, much used in the later Gothic work as an ornamental reature.

Diaper Work.—Is the name given to bands, surfaces and panels in the stone work formed by square stones and similar squares, filled in with brick or flint work, giving a chequered appearance, as shown in Figures 208 and 209. The term is also supplied to any ornament arranged in squares upon the surface of ashlar masonry.

Tympanum.—The masonry filling in between the relieving arch and the head of a door or window. Advantage is often taken of this to form a ground for carved ornament, as shown in Figure 213.

Gargoyle.—Is a stone water-spout, as shown in Figure 218, employed in buildings of Gothic character to carry off the rain from the gutters. These project sufficiently far to throw the water clear of the building. At present down pipes are employed, but the gargoyle is often retained as an overflow in lieu of a warning pipe.

Tailing Irons.—These are formed of H, L or T irons for holding down the ends of corbels in oriel windows, as shown in Figure 220.

Lintels.—Wide spans requiring to be bridged by stone lintels (as is the case in the trabeated styles of architecture) are often of a greater dimension than can be conveniently obtained in one stone, in which case the lintel is built up in one of two ways.

(1) By an arched construction, as shown in Figure 467. The sloping joints in this method are considered objectionable by some, altering as it does the principle of the construction from the beam to the arch, the number of small pieces detracting from the general effect. Vertical joints are preferred to inclined. The arched principle, with vertical jointed voussoirs, may be carried out by forming the joint vertically on and about 4 inches below the face and the remainder to the back, or, if seen on both sides, in the

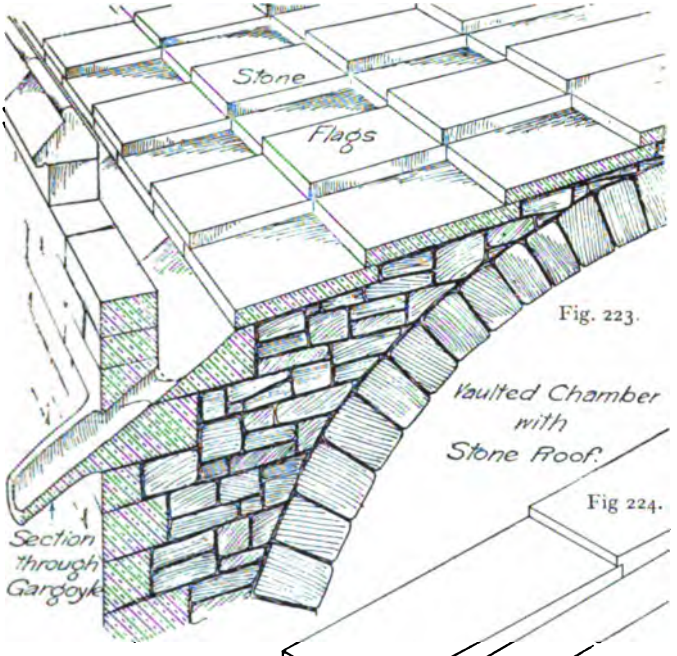


Fig. 223.

Fig 224.

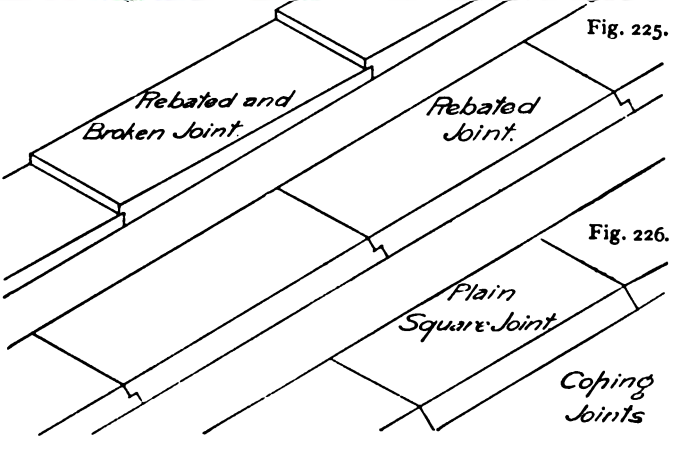


Fig. 225.

Fig. 226.

centre of the lintel. The stones cut thus form voussoirs of an arch, as shown in Figure 227.

Fig. 227.

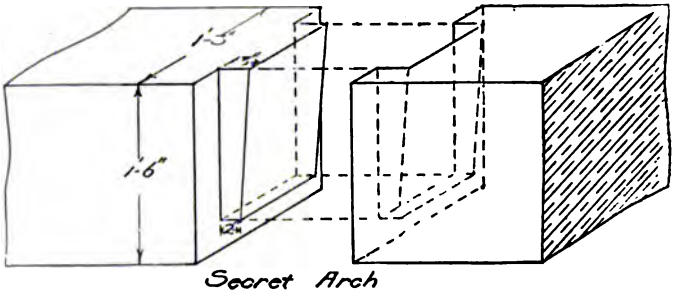
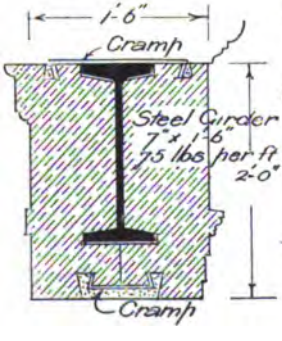


Fig. 228.



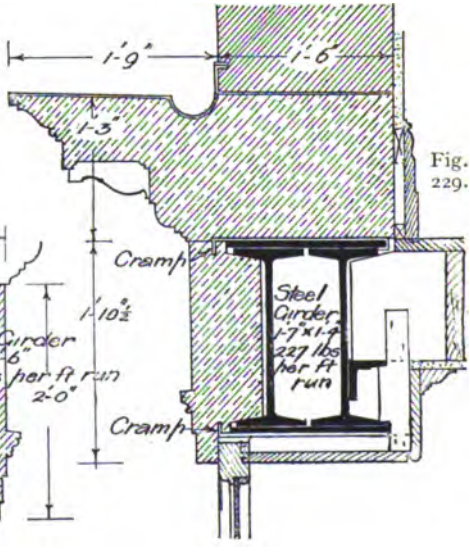


Fig. 229.

(2) The method now most usually adopted is to build the lintel up of a number of pieces with vertical joints and in two thicknesses, the front and back portion being made,

as shown in Figure 228, to envelop the flanges of a steel girder, which bridges the whole span and takes its bearing on the columns. The back and front pieces are connected on the soffit, and the upper surface by small copper cramps, the latter being bedded in cement mixed with dust from the stones to be united. The whole soffit is finally rubbed over with a piece of stone similar to the lintels, to render the joint as nearly as possible invisible. Care must be taken to protect the iron girder from the danger of oxidation by applying one of the preservative processes employed for iron and steel.

The stone entablatures built over shop fronts are formed in this way, but have the stone on one side only of the girder, being connected to the same with cramps, as shown in Figure 229.

The masonry above stone lintels should be disposed, to throw as much as possible the weight of the superimposed walling on to the supports, and not unnecessarily stress the lintel.

Labours.—The following are the chief labours adopted in preparing stonework:—

Half Sawing.—The surface left by the saw. Half the cost of the sawing being charged to each part of the separated stone.

Self-Faced.—The term applied to the quarry face, or the surface formed when the stone is detached from the mass in the quarry; also the surfaces formed when a stone is split in two.

Scabbling or Scappling.—That is, taking off the irregular angles of stone; is usually done at the quarry, and is then said to be quarry pitched, hammer faced or hammer blocked; when used with such faces the stone is called rock or rustic work.

Hammer Dressing.—Roughest description of work after scabbling, as shown in Figure 230.

Chisel Draughted Margin.—To ensure good-fitting joints in hammer-faced stones, a true surface about an inch wide is cut with a chisel, forming a margin on the face of stone, as in Figure 231.

Plain Work.—This is divided, for purposes of valuation, into half plain and plain work. The former term is used when the surface of the stone has been brought to an approximately true surface, either by the saw or with the chisel. Plain work is the term adopted for surfaces that have been taken accurately out of winding with the chisel. Half plain is usually placed upon the bed and side joints of stones in ashlar work and plain work on the face.

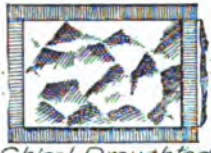
Rubbed Work. — This labour consists in rubbing the surfaces o. stones until perfectly regular, and as smooth as possible. The work is accomplished by rubbing a piece of stone with a second piece. During the first stages of the process, water and sand are added, gradually reducing the quantity of sand up to the finish. Large quantities of stone are rubbed by means of large revolving iron discs, on which the stones are placed, and kept from revolving with the disc by means of stationary timbers fixed a few inches above and across the table. Water and sand are added to accelerate the process. Only plane surfaces can be rubbed in this way.

Polishing. — Marbles, after the rubbed operation, are brought to a still smoother surface by being well rubbed with flannel and a paste of bees'-wax and turpentine or putty. The polishing of granites has been described in the chapter on Stones.

Boasted or Droved Work.—This consists in making a number of parallel chisel marks across the surface of the stone by means of a chisel, termed a boaster, which has an edge about $2\frac{1}{2}$ inches in width. In this labour, the chisel marks are not kept in continuous rows across the whole width of the stone, as shown in Figure 232.

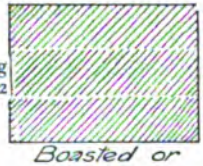
Fig. 230. Hammer Dressed.

Fig. 231.



Chisel Draughted Margins.

Fig 232



Boasted or Droved.

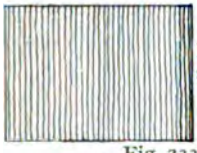


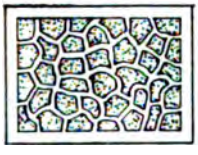
Fig. 233. Tooled.

Fig. 234.

Combed or Dragged.

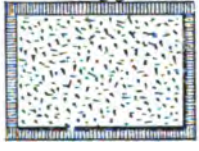
Fig. 235.

Furrowed.



Vermiculated.

Fig. 236.

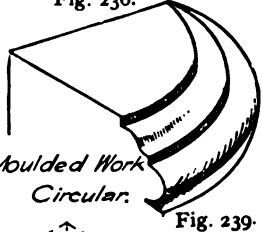


Pointed.

Fig. 237.

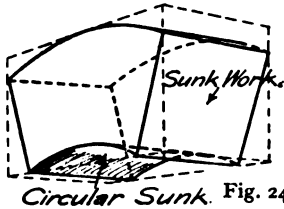
Moulded Work.

Fig. 238.



Moulded Work Circular.

Fig. 239.



Sunk Work.

Circular Sunk.

Fig. 240.

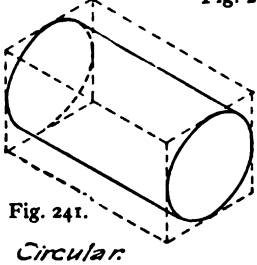
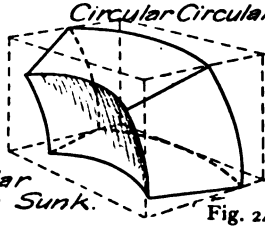


Fig. 241.

Circular.



Circular Circular.

Circular Circular Sunk.

Fig. 242.

Tooled Work.—This labour is a superior form of the above, care being taken to keep the chisel marks in continuous lines across the width of the stone, as shown in Figure 233. The object of this and the preceding is to increase the effect of large plane surfaces by adding a number of shadows and high lights. This labour in Scotland is sometimes known as scabbled work.

Axed Work.—Axed work and tooled work are similar labours. The axe is employed for hard stones, such as granite, but the mallet and chisel for soft stones, being more expeditious.

The method of preparing the hard stones after being detached from their beds in the quarry is as follows:—The stones are roughly squared with the spall hammer; the beds are then prepared by sinking a chisel draught about the four edges of the bed under operation, the opposite draughts being out of winding, and the four draughts in the same plane surface; the portions projecting beyond the draught are then taken off with the pick. After the pick the surface is wrought with the axe, the latter being worked vertically downward upon the surface, and taken from one side of the stone to the other, and making a number of parallel incisions or bats, the axe is worked in successive rows across the stone, the incisions made being kept continuous across the surface. In axed work there are about four incisions to the inch. This labour is used for the beds of stones for thresholds and kerbstones, and in this state the pick marks are easily discernible. Fine axed work is a finer description of axed work, and is accomplished with a much lighter axe having a finer edge. In fine axed work there would be eight incisions to the inch.

Furrowed Work.—Shown in Figure 235. This labour, used to accentuate quoins, consists in sinking a draught about the four sides of the face of a stone, leaving the central portion

projecting about $\frac{3}{8}$ inch, in which a number of vertical grooves about $\frac{3}{8}$ inch wide are sunk.

Combed or Dragged Work.—Shown in Figure 234. This is a labour employed to work off all irregularities on the surfaces of soft stones. The drag or comb is the implement used. It consists of a piece of steel with a number of teeth like those of a saw. This is drawn over the surface of the stone in all directions, making it approximately smooth.

Vermiculated Work.—This labour is placed chiefly on quoin stones to give effect. The process is as follows: A margin of about $\frac{3}{4}$ inch is marked about the edge of the stone, and in the surface enclosed by the margin a number of irregularly shaped sinkings are made. The latter have a margin of a constant width of about $\frac{3}{8}$ inch between them. The sinkings are made about $\frac{1}{4}$ inch in depth. The sunk surface is punched with a pointed tool to give it a rough pock-marked appearance, as shown in Figure 236.

Pointed Work.—The bed and side joints of stones are often worked up to an approximately true surface by means of a pointed tool or punch. This labour is often employed to give a bold appearance to quoin and plinth stones, and where so used it usually has a chisel draughted margin about the perimeter, as shown in Figure 237.

Moulded Work.—Mouldings of various profiles are worked upon stones for ornamental effect, as shown in Figure 238. Mouldings are worked by hand as well as by machine. In the former case, the profile of the moulding is marked on the two ends of the stone to be treated by means of a point drawn about the edge of a zinc mould, cut to the shape of the profile. A draught is then sunk in the two ends to the shape of the required profile. The superfluous stuff is then cut away with the chisel, the surface between the two draughts being tested for accuracy by means of straight-edges. The machines for moulded work somewhat resemble the planing machines for metal work. The stone is fixed

to a moving table. The latter has imparted to it a reciprocating rectilinear motion, pressing against a fixed cutter of the shape of required profile, or some member of it. The cutter is moved near to the stone after each journey, thus gradually removing the superfluous stuff till the profile is completed. Moulded work is, strictly speaking, the name given to profiles formed with a change of curvature, and, therefore, should not be applied to cylindrical sections, such as columns.

The weathering properties of stones moulded by hand labour are considered by some far superior to those worked by machinery, as in the latter method the moulding irons, being driven continuously, become heated and partially calcine the surfaces of the stones, thus rendering it peculiarly susceptible to atmospheric deterioration.

Moulded Work, Circular.—This term is given to mouldings, as shown in Figure 239, stuck upon circular or curved surfaces in plan or elevation.

Sunk Work.—This term is applied to the labour of making any surface below that originally formed, such as chamfers, wide grooves, the sloping surfaces of sills, etc., as shown in Figure 240. If the surface is rough, it is known as half-sunk; if smooth, sunk; and any other labour applied must be added, such as sunk, rubbed, etc.

Circular Work.—Labour put upon the surface of any convex prismatic body, such as the parallel shaft of a column or large moulding, is termed circular work, as shown in Figure 241.

Circular Sunk Work.—Labour put upon the surface of any concave prismatic body, such as a large hollow moulding or the soffit of an arch, is termed circular sunk work, as shown in Figure 240.

Circular Circular Work.—The labour placed upon columns with entases, spherical or domical work, as shown in Figure 242.

Circular Circular Sunk.—The labour worked upon the interior concave surfaces of domes, etc., as shown in Figure 242.

Internal Mitres.—The name given to the intersection of two mouldings making an angle less than 180 degrees.

External Mitres.—The name given to the intersection of two mouldings making an angle greater than 180 degrees.

Returned Mitred and Stopped.—The name given to a moulding returned in itself, and stopping against an intersecting surface.

Long and Short Work.—This work is often used for quoins and dressings in rubble walls, and is especially noticeable in old Saxon work. It consists in placing alternately a flat slab, which serves as a bonder, and a long stone approximately small and square in section.

This arrangement in modern work is sometimes known as block and start work.

Stone Walling.—Is divided under the following headings :

1. Rubble. 2. Block in Course. 3. Ashlar.

Rubble walls are those built of thinly-bedded stone, generally under 9 inches in depth, of irregular shapes as in random rubble, or squared as in coursed rubble.

Block in course is composed of squared stones usually larger than coursed rubble, and under 12 inches in depth.

Ashlar is the name given to stones, from 12 to 18 inches deep, dressed with a scabbling hammer, or sawn to blocks of given dimensions and carefully worked to obtain fine joints.

The length of a soft stone for resisting pressure should not exceed three times its depth; the breadth from one-and-a-half to twice its depth; the length in harder stones four to five times its depth, and breadth three times its depth.

Random Rubble.—The name given to walling built of

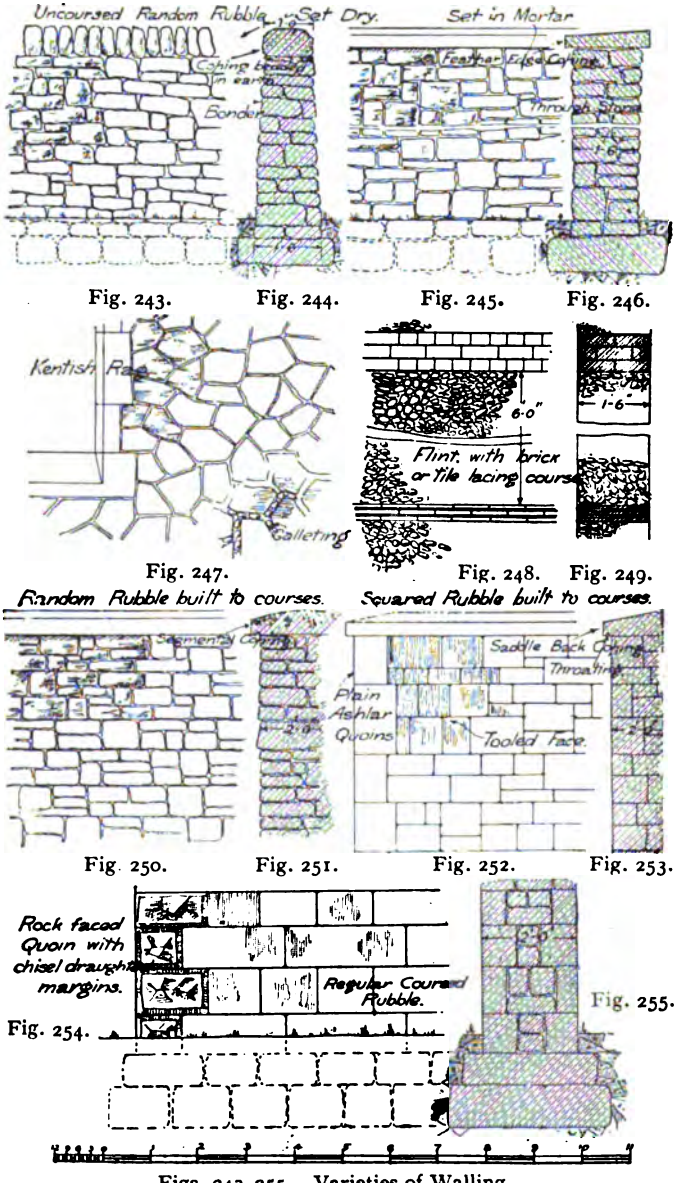


Fig. 243. Fig. 244. Fig. 245. Fig. 246.

Fig. 247. Fig. 248. Fig. 249.

Fig. 250. Fig. 251. Fig. 252. Fig. 253.

Fig. 254. Fig. 255.

Figs. 243–255. Varieties of Walling.

stones that are not squared, but roughly fitted with a waller's hammer.

Random Rubble set Dry.—In the stone districts boundary walls are built of rubble set without mortar. The top is built of heavy stones which are usually bedded in earth, as shown in Figures 243 and 244, to prevent slight movement.

Uncoursed Random Rubble set in Mortar.—As shown in Figures 245 and 246, the stones are used as they come from the quarry, care being taken to obtain them as uniform as possible, and roughly fitting with the waller's hammer; one bond stone is used in every super yard on face; any openings between stones to be pinned in with spalls. If good mortar is used, walls built of random rubble should be made one-third thicker than the thickness necessary for brick walls.

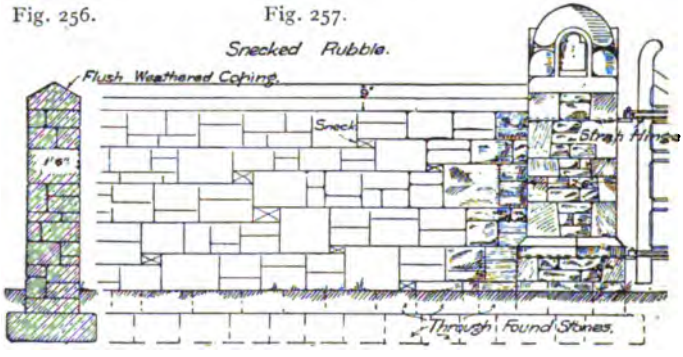
Kentish rag stone is an unstratified stone found in Kent, and is used largely in that district. The stones are roughly fitted with a waller's hammer, and assume on face regular polygonal forms. Figure 247 shows an elevation of this type of random rubble walls.

Random Rubble built in Courses.—This, illustrated in Figures 250 and 251, consists of stones forming horizontal beds at intervals of 12 to 18 inches, every stone being bedded in mortar. The object of coursing is to ensure that there shall be no continuous vertical joints. To save expense in bedding each stone in mortar, masons bed only the stones on faces of wall, and at these levels pour a pail of thin mortar, called grout, to fill up any cross joints between stones, taking care that the hearting stones are properly interlocked.

Uncoursed Squared or Snecked Rubble.—Stones roughly squared and hammer or axe faced, the vertical depth of the stones usually being less than 9 inches; to prevent continuous long horizontal joints, small stones, termed snecks, are placed

at intervals as shown in Figure 257, adjacent to a large stone, the beds of both being level and thereby commencing

Fig. 256. Fig. 257.



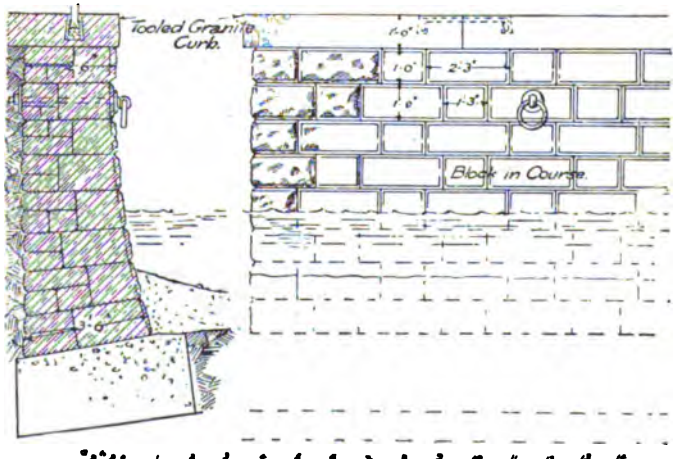
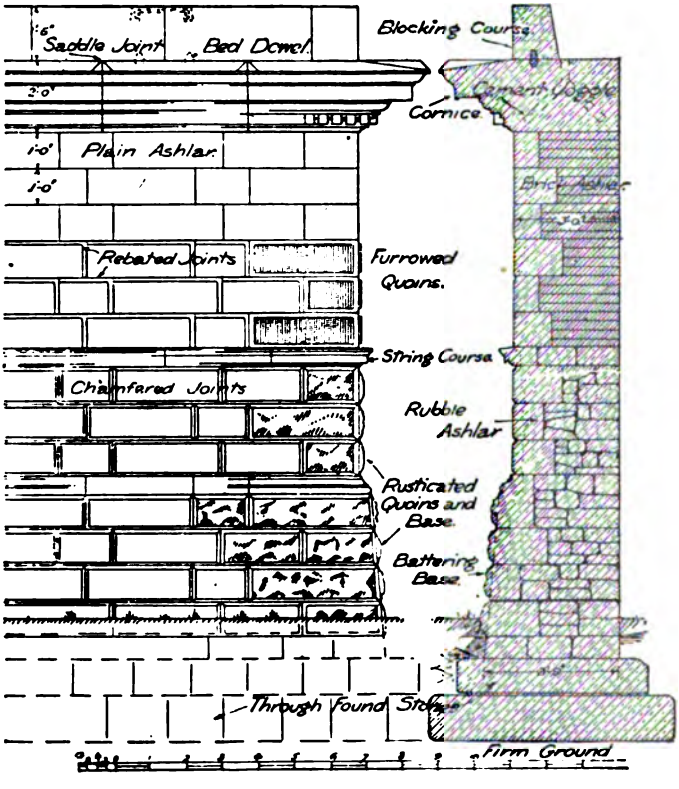


Fig. 258. Fig. 259.

a horizontal joint at another level. See specification at the end of this chapter.

Squared Rubble built in Courses.—Figures 252 and 253 show squared rubble brought up to level beds with dressed quoins. The coursing is to prevent continuous vertical

Fig. 260. Fig. 261.



joints. It is sometimes known as irregular coursed rubble, as the courses need not all be of a uniform depth.

Regular Coursed Rubble.—In this kind of work all stones in one course are squared to the same height, usually

varying from 4 inches to 9 inches, as illustrated in Figures 254 and 255, and are generally obtained from thin but regular beds of stone.

Block in Course is the name applied to stone walling, chiefly used by engineers in embankment walls, harbour walls, etc., where strength and durability are required. The stones are all squared and brought to good fair joints, the faces usually being hammer-dressed, as shown in Figures 258 and 259. Block in course closely resembles coursed rubble, or ashlar, according to the quality of the work put upon it.

Ashlar.—Ashlar is the name applied to stones that are carefully worked, and are usually over 12 inches in depth.

As the expense would be too costly to have walls built entirely of ashlar, they are constructed to have ashlar facing and rubble backing, or ashlar facing and brick backing, both shown in Figures 260 and 261; but, as the backing would have a greater number of joints than the ashlar, the backing should be built in cement mortar, and brought to a level at every bed joint of the ashlar, to ensure equality of settlement.

The ashlar facing may be plain, rebated, or chamfered, as illustrated in Figure 260, and looks best when laid similar to Flemish bond in brickwork.

Joints.—In arranging the joints of masonry, the following general principles should be observed:—

(1) All the bed joints must be arranged at right angles to the pressure coming upon them.

(2) Joints should be arranged to prevent any members, such as sills, being under a cross-stress.

(3) The joint should be arranged so as to leave no acute angles on either of the pieces joined.

The first condition applies to all kinds of masonry. It is necessary to prevent any sliding tendency taking place between the stones.

The second condition applies chiefly to sills in window openings. These, if in one piece and built into the piers at each side of the opening, are often subjected to a cross-stress, owing to the settlement being greater under the piers than beneath the window openings. This danger occurs more frequently in openings in the lowest storey, and the effect of it is to break the sill. In brickwork, this defect is remedied by fixing the sill after the whole of the brickwork has been erected and the settlement taken place; but in stonework, and under conditions where the sill must be fixed as the building proceeds, the breaking of the sill may be prevented by having a vertical joint in the line of the face of the reveal, as shown in Figure 473.

If there are any heavy mullions down which pressure may be transmitted, the same precaution must be taken with the sill; but if light mullions occur, the sill may be taken continuously through. In such cases no joint in the sill should occur under the mullions.

The third condition applies chiefly to the joints in tracery work, and any exposed joints in any other work. Stone being a granular material, anything approaching an acute angle is liable to weather badly, therefore in any tracery work having several bars intersecting, a stone must be arranged to contain the intersections and a short length of each bar, as shown in Figure 473, and the joints should be (*a*) at right angles to the directions of the abutting bars if straight, or (*b*) in the direction of a normal to any adjacent curved bar. This not only prevents any acute angles occurring, as would be the case if the joints were made along the line of intersection of the moulding, but also ensures a better finish, as the intersection line can be carved more neatly with the chisel, and is more lasting than would be the case if a mortar joint occurred along the above line. In no case, either in tracery, string courses, or other mouldings, should a joint occur at any mitre line.

Joints.—These may be classified as follows :—

(1) To resist compression such as the square joint, the surface of which is arranged normal to the pressure.

(2) To resist tension, cramps, lead plugs and bolts.

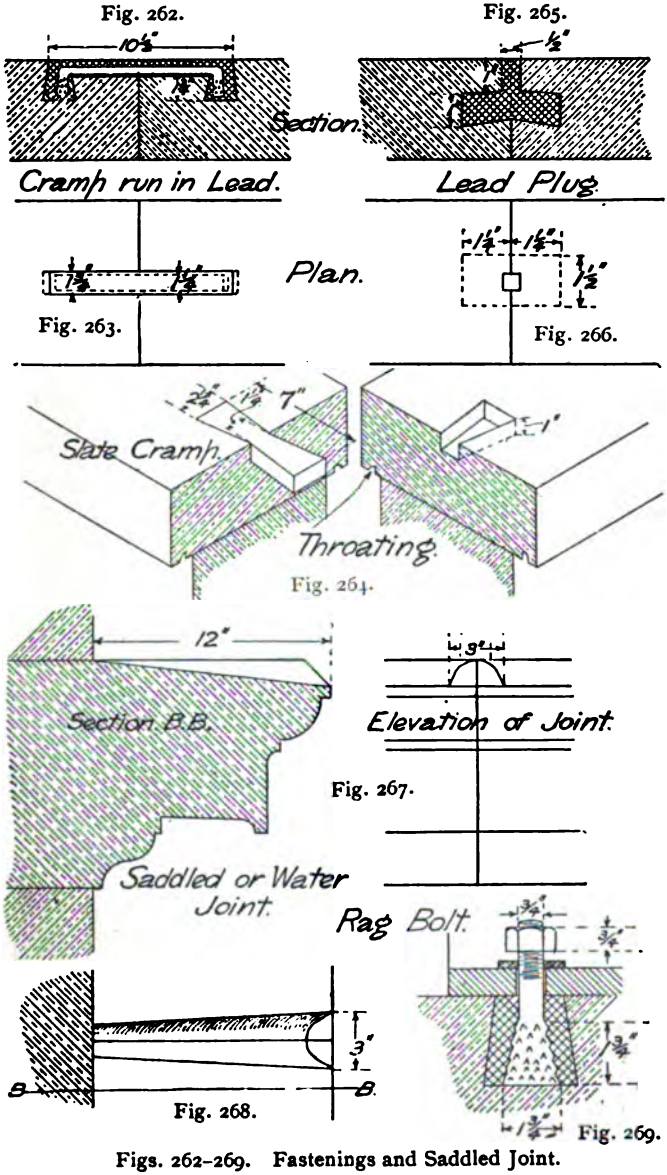
(3) To resist sliding or displacement, joggle joints, tabling dowels and pebbles.

Joints to resist Compression.—Joints in stone under a compressional stress have plane abutting surfaces normal to the stress.

Joints to resist Tension.—The texture of stone is unsuited to form tensional connections. Where there is any tensional stress the joints are best held together by metal connections.

Cramps.—Metal cramps are used to bind work together, and are particularly adapted for positions in which there is a tendency for the stones to come apart, such as in copings covering a gable, or in face stones of no great depth, or cornices and projecting string courses to tie them to the body of the wall. The cramps are made from thin pieces of metal of varying lengths and sectional area according to the work, turned down about $1\frac{1}{2}$ inches at each end. The ends are made rough and inserted into dovetailed shaped mortices, and the body in a chase made to receive them in the stones to be connected, as shown in Figures 262 and 263. The cramps are usually prepared from either wrought iron, copper, or bronze. If wrought iron is used, it is usually subjected to some preservative process, such as tarring and sanding or galvanising, to prevent oxidation. Iron is useful on account of its great tensile strength. Copper is valued for its non-corrosive properties under ordinary conditions, and its tensile strength, which is not much less than wrought iron; it is, however, comparatively soft. Bronze possesses all the properties of copper necessary for cramps, and in addition is much harder, and therefore better.

The best bedding materials are Portland cement, sulphur



Figs. 262–269. Fastenings and Saddled Joint.

and sand, asphalte and lead. Care should be taken to completely envelop the cramp in the bedding material. Stones are also connected by slate cramps set in cement, as shown in Figure 264.

Lead Plugs.—Stones may be connected together by means of lead in the following manner, shown in Figures 265 and 266 :—Dovetailed-shaped mortices of the form shown are made to correspond in the side joints of two adjacent stones, into which, when placed in position, molten lead is poured, and when cool is caulked, thus completely filling the mortices and connecting the pieces.

Bolts.—Stone pinnacles, finials, and similar members, where built of several stones, are usually connected together with iron bolts passing through all of them and binding down to some more stable portion of the work. Cornices with a great projection are secured by long iron bolts, termed anchor bolts, carried well down into the body of the work, and at their lower ends passing through large iron plates termed anchor plates.

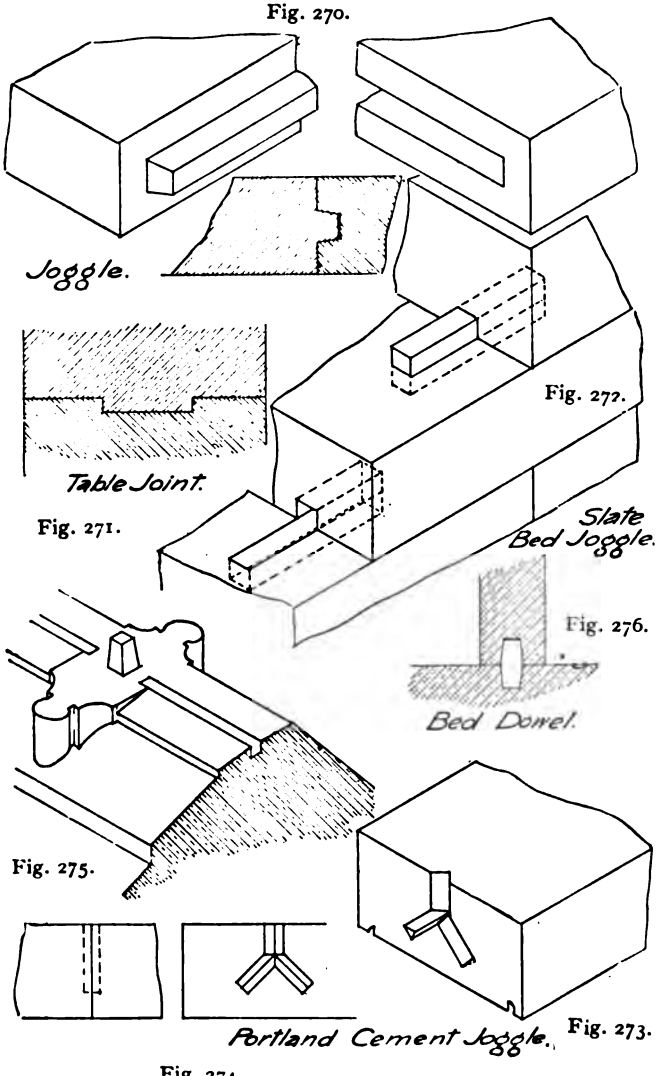
Rag Bolts.—As shown in Figure 269, are employed to secure ironwork to stone. The ends of the bolts are often fixed by having the end that is let into the stone jagged, and run with lead, or sulphur and sand, the mortice being dovetail-shaped to secure it from any upward pressure.

Where there is any probability of a great upward stress a hole is drilled right through the stone and a bolt supplied with a washer passed through in the ordinary manner.

Joints to Resist Sliding.—The following are those most used :—

Joggles.—A joggle is a form of joint in which a portion of the side joint of one stone is cut to form a projection, and a corresponding sinking is made in the side of the adjacent stone for the reception of the projection, as shown in Figure 270. It is chiefly used in landings, to prevent

Fig. 270.


Joggle.
Table Joint.
Fig. 271.
Fig. 272.
Slate Bed Joggle.
Fig. 276.
Bed Dowel.
Fig. 275.
Portland Cement Joggle.
Fig. 273.
Fig. 274.

any movement between the stones joined and so retain a level surface between them, and also to assist in distributing any weight over every stone in the landing.

Tabling Joints.—This is a form of joint that has been used to prevent lateral motion in the stones of a wall subjected to lateral pressure, such as in a sea-wall. It consists of a joggle joint in the bed joints, the projection in this case being about 1½ inches in depth and a third of the breadth of the stone in width, as shown in Figure 271. This kind of joint is rarely used now owing to the great expense in forming it, it being superseded for sea-walls by huge blocks of concrete cast on or near the spot, of a weight sufficient to resist any pressure likely to be brought to bear on them, and usually under other conditions by long slate joggles placed in a space to receive them in the bed joint at the junction of side joints of two stones and the top bed joint of another, as shown in Figure 272. These were used in the piers of the new Tower Bridge.

Cement Joggles.—These are generally used in the side joints of the top courses of masonry to prevent lateral movement in them, and consist of a V-shaped sinking in the side joint of each adjacent stone in the same course, as shown in Figures 273 and 274.

Dowels.—Dowelling is another method of obtaining the same result as joggling or tabling. The dowels consist usually of pieces of hard stone or slate about 1 inch square in section, and varying from about 2 inches to 5 inches in length, slightly tapering from the centre towards the two ends, as shown in Figures 275 and 276, being sunk and set in cement in corresponding mortices in the adjacent stones. They are used in both the side and bed joints. They are generally employed in the top courses of masonry where the weight on or of the individual stones is not great. The united mass thus formed from the collected stones renders any movement impossible under normal conditions.

Pebbles.—Small pebbles, owing to the ease with which they may be fitted, were formerly commonly employed in the joints of stones to prevent sliding. They are now in most work displaced by slate dowels or joggles. The pebbles are still sometimes used for small work.

STONE STAIRS.

Stone Stairs consist of a number of blocks, fixed at regular and convenient heights, to facilitate transit between planes of different levels, and are of three kinds: (1) Those stairs supported at both extremities; (2) those fixed at one end (the other end being left free), and known as hanging steps; (3) steps circular in plan. These latter are divided into two classes: (1) Those with a central newel; (2) those with an open well.

The steps may be in one of two forms, either rectangular or spandrel, as shown in Figure 277. In the commoner stairs the rectangular blocks are used, but where a good appearance is desired, or to gain headroom, spandrel steps are employed. The spandrel steps may be finished in one of three ways: (1) with a plain soffit, which consists in finishing the soffit in one plain surface, as shown in Figure 277; (2) a broken soffit may be employed, as shown in Figure 277 (this is used for one of three reasons, or for all combined: (*a*) to gain strength at the back of the tread; (*b*) to save the expense incurred in working the surface of each step perfectly level; (*c*) to obtain effect); (3) having the soffit moulded.

Each step may simply rest upon the one below it, but it is usual for the upper step to be rebated over the back of the one below to prevent sliding. To avoid acute angles at this point, and to form an abutting surface, particularly in the spandrel steps, a chamfer is taken off the top back edge of the lower step at right angles to the

pitch of the stairs, the upper step having a corresponding sinking to fit. This is known as a back joint, and is shown in Figure 277.

Fixing the Steps.—Stone stairs are erected in one of two ways: (1) They may be built in the walls as the latter are built, or (2) spaces may be left in the walls to receive the ends of the steps, which are fitted and fixed when the wall is finished. The wall should be built in cement mortar for at least 12 inches above and below the line of the stairs, the gaps to receive the stairs being temporarily filled up by brickwork bedded in sand.

The ends of the steps should be pinned in the walls with tiles or slates set in cement, care being taken that the space left about the end of the step is filled up, as far as possible, with solid material, leaving no thick mortar joints to squeeze out. While the step is setting, the outer or free end should be supported with wood struts, after being levelled, which should remain until the cement has thoroughly set.

The first kind of stair, viz., those supported at both ends, combine convenience with the greatest strength. They are much used in schools, theatres, and other public buildings. They are usually made of rectangular steps, which rest 6 inches on the wall at either extremity.

The second kind, or hanging steps: these are much superior in appearance to those last described. They derive their chief support from the walls, but each step receives an additional amount from the one directly beneath it. These are used for all conditions of stairs, from the secondary staircases in dwelling-houses to the grand staircases in public buildings. In the commoner kinds, rectangular steps are used; but in the superior, spandrel steps are always employed.

The steps may be plain or have moulded nosings; where the latter are employed, the moulding should be returned

about the free end, the moulding on the latter being returned and stopped directly beneath the riser of the steps above, as shown in Figure 277.

When the staircases are very wide, it is advisable to support the steps at their outer ends by steel joists or cantilevers at intervals, the strength of stone under cross stress not being very great. Figure 277 shows a landing supported by a joist.

The first of the third class of stair, the circular newel, is used for turret steps; they are built in a circular chamber. The steps are wedge-shaped, their thin end being worked circular to a radius of about 3 inches, the front edge of each step being tangent to this circle, the back edge of the step being a radial line. The steps are built into the walls of the chamber, at their wide ends, each of the circular ends being arranged to fall directly over the one beneath it, thus forming a continuous newel up the centre. These form a strong stair, but are rather dangerous, as they have to be steeply pitched to gain the necessary headroom.

Secondly, those formed with an open well are built in the same manner as the hanging stair, of which they form one variety. Stairs, circular and elliptical in plan, are often built between two walls, as in the first class of stair.

Large stone landings which cannot be obtained out of one piece of stone are joggled at their joints, and where the slabs are thin, and are likely to be subjected to heavy traffic, should be supported by steel girders.

The balusters in stone staircases are always of iron, which is better for fixing purposes. There are two methods of fixing balusters: (1) Fixing them into the top, suitable for standard balusters, as shown in Figure 277; (2) fixing them into the side, when they are termed bracket balusters; as shown in Figure 277. Holes are bored in the steps at the proper intervals, being slightly undercut. The ends of the

balusters are indented before being inserted; they may be fixed in with lead, Portland cement, sulphur, and sand, or asphalte, as previously described.

Figures 277 and 278 show plan, elevation, and details for an open well hanging stair, built of Portland stone. The lower flight shows handrail supported by standard balusters, the upper portion with bracket balusters to obtain the maximum quantity of available stair space. The method of setting out a scroll and curtail step is shown.

Stone Roof.—Figures 218 to 220, show the method of arranging the stone roof over an oriel window. Figure 223 shows the method of forming a stone-covered roof over a vaulted chamber, such as was frequently used during mediæval times in military and monumental buildings. It is formed of stone flags bedded on rubble filling over the vault. In these roofs the flags are laid in two systems, the lower and the upper: in the first the flags are spaced apart, in the second the flags are bedded with a lap of 2 or 3 inches over the top edges of the flags in the first system. The whole upper surface has a slight fall for drainage.

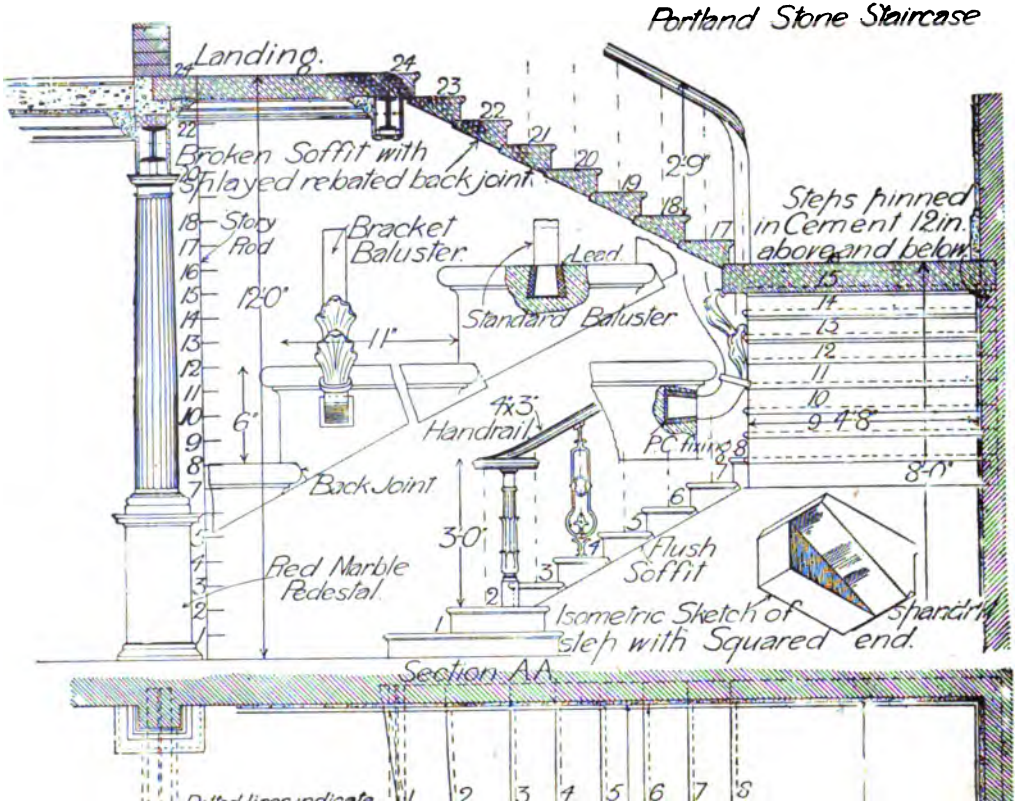
Mouldings.—Mouldings may be classified under two heads, Classic and Gothic. The Classic are those derived from those employed by the Greeks and the Romans. Invariably the Roman mouldings are found to have their prototype in the Grecian examples, the chief difference being that the Greek are either segments of some of the conic curves or are struck freehand, while the Roman curves are all segments of circles.

There are nine typical examples, as follows:—

(1.) *Fillet.*—This is a narrow flat projection often used to divide individual or groups of mouldings in any composition; it is similar in both Greek and Roman work, as shown in Figure 283.

(2.) *Astragal* is a small semicircular moulding, as shown in Figure 284, often used in combinations of mouldings,

Fig. 277.


Portland Stone Staircase
Landing.
Broken Soffit with Splayed rebated back joint
Story Rod
Bracket Baluster.
Lead
Standard Baluster
12'0"
11"
6"
4"x3" Handrail
P.C. fixing
Back Joint
3'0"
Red Marble Pedestal
Flush Soffit
Isometric Sketch of Spandril step with Squared end.
2'9"
Steps pinned in Cement 12in. above and below
4'8"
8'0"
Section A.A.

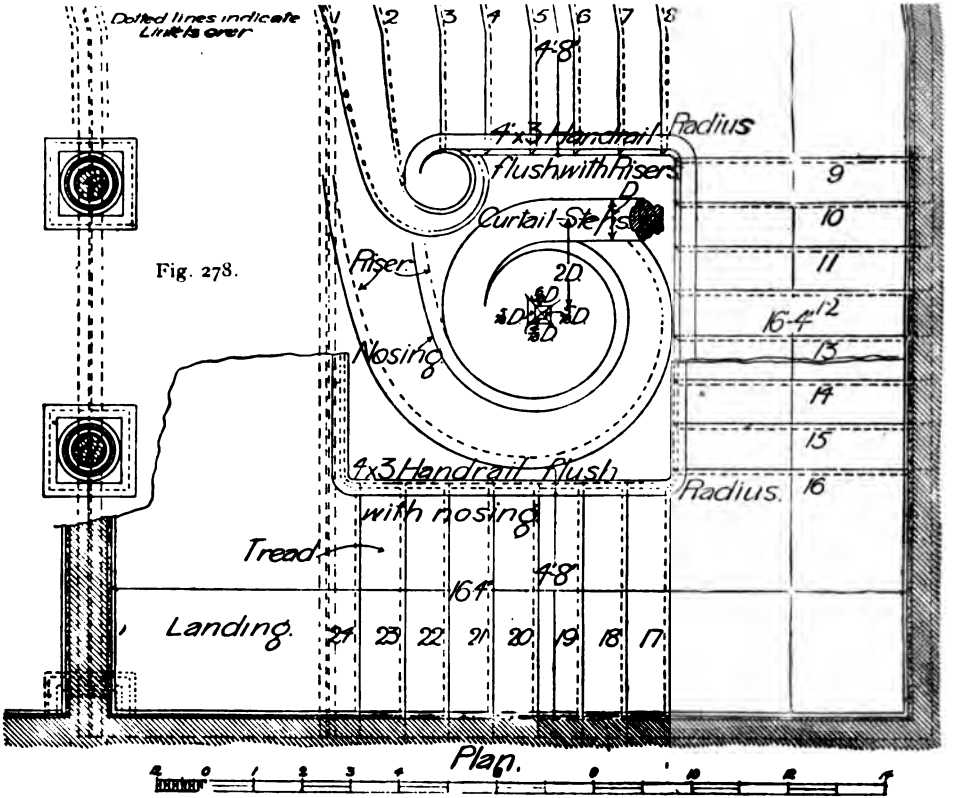


Fig. 278.

Figs. 277-278.

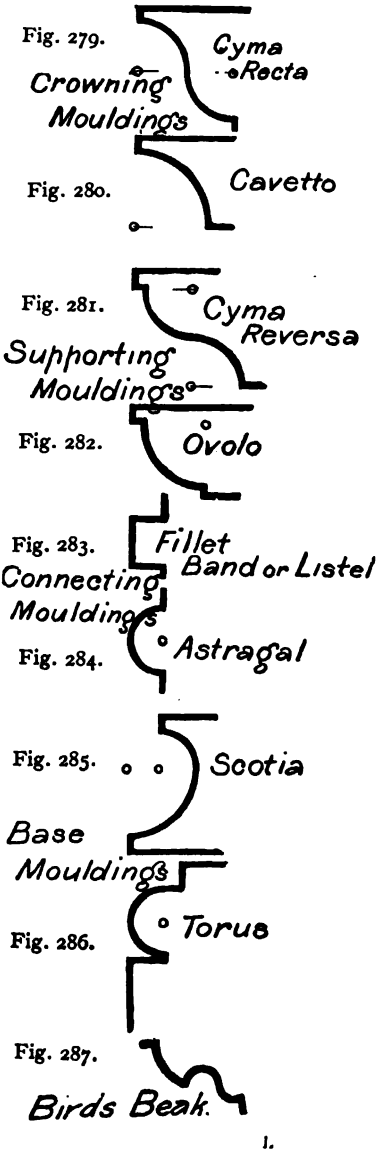
[*Between pages* 146 *and* 147.

but chiefly to mark the division between the shafts and caps of columns. This member is similar in Greek and Roman.

(3.) *Cavetto.*—The cavetto is a hollow moulding, as shown in Figure 280, consisting in the Greek of a quarter of an ellipse and in the Roman of a quadrant.

(4.) *Ovolo.*—This moulding in the Greek consists of a segment of an inclined ellipse, having a fillet at the top and bottom, and forming at the top a quirk. In Roman work, as shown in Figure 282, it is a quarter circle, bounded at top and bottom by a fillet.

(5.) *Cyma Recta.*—This is a double curve, formed in the Greek of two quarter ellipses whose minor axes are in the same straight line and bounded top and bottom by a fillet. The Roman example, as shown in Figure 279, is



similar, but consisting of two quarter circles. This moulding has a concave portion of its surface above the convex, and is generally used as a crowning member.

(6.) *Cyma Reversa.*—As its name implies, is the reverse of the preceding moulding, slightly modified in the Greek by having a quirk above, between the same and the fillet, and the hollow portion slightly more concave. The Roman is an exact reverse, as shown in Figure 281.

(7.) *Scotia.*—The scotia in the case of the Greek is formed of an inclined ellipse, having a fillet above and below. The Roman is struck from two centres on a common radial line, as shown in Figure 285.

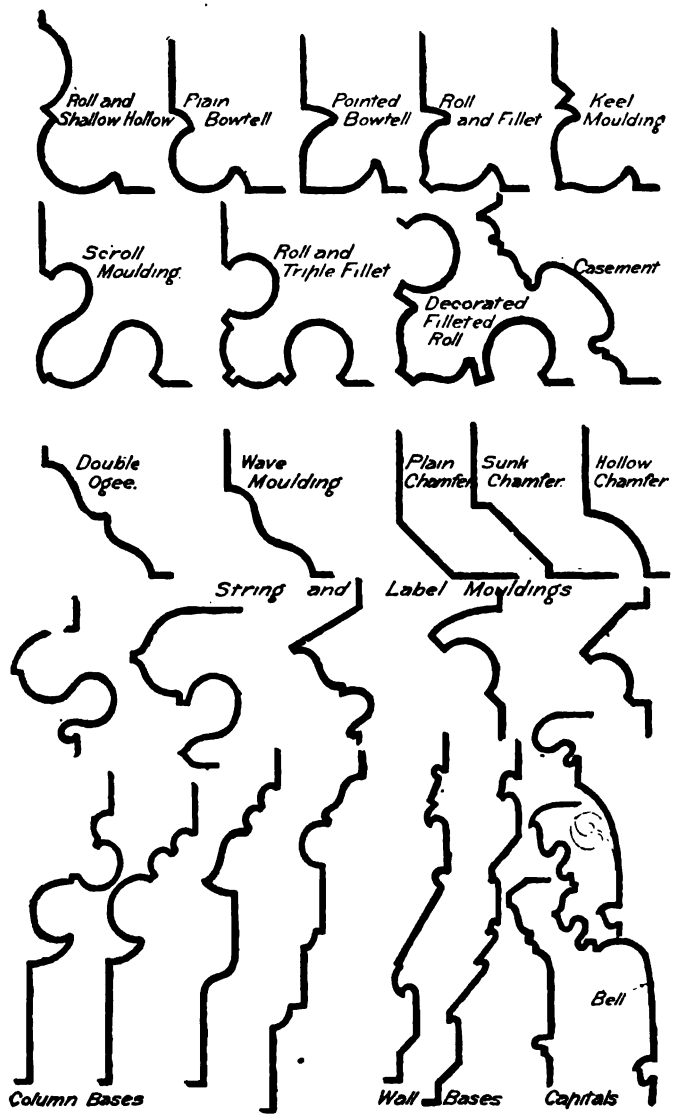
(8.) *Torus.*—The torus is a base moulding, the Greek form being the reverse of the scotia. Many Greek examples are, however, similar to the Roman, consisting simply of a large semicircle with a quirk below and a fillet above, as shown in Figure 286.

(9.) *Bird's Beak.*—This moulding only occurs in the Greek mouldings; it consists of a quarter ellipse (with the major axis horizontal), in the lower side of which a small hollow has been worked, as shown in Figure 287, and is used as a supporting moulding.

In the designing of groups of mouldings for cornices, strings, etc., reference should be made as to the suitability of the forms for their intended position, and for this purpose they may be divided into base mouldings, connecting mouldings, supporting mouldings, and crowning mouldings. The base mouldings would include such mouldings as the torus, the scotia or the inverted cyma recta, and any combination of such mouldings that would tend to broaden the base and distribute the weight of the mass supported.

Connecting.—These include the fillet and the astragal.

Supporting.—The supporting mouldings include such members as the ovolo, bird's beak and the cyma reversa, mouldings that do not have their hollow members near



Figs. 288-315. Types of Gothic Mouldings.

their upper edge, and such as have their mass in a position to strengthen them, and are fitted to act as corbels. These mouldings are used to form the bed mouldings or lower parts of combinations, such as cornices which are divided into two parts, the bed mouldings and the crowning mouldings.

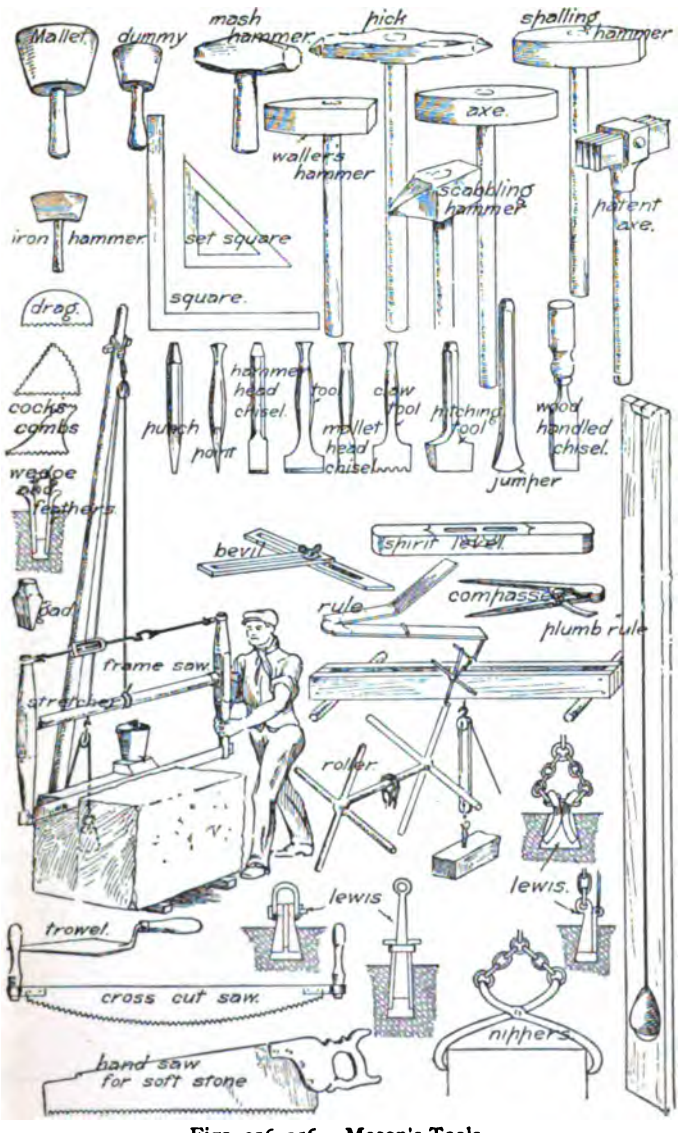
Crowning Mouldings are those mouldings which are not expected to carry anything above, such as the cyma recta and the cavetto, the top members of which are small and delicate.

The above ideas are not always rigidly adhered to, and successful departures from them are often made with good effect; but it is prudent to bear these principles in mind when designing any groups, for if too widely departed from, confusion ensues.

Gothic Mouldings.—Figures 288 to 315 give a selection of the mouldings commonly used in the Gothic periods, combinations in archivolts, also for strings, wall bases, bases and capitals of columns.

Tools.—Figures 316 to 356 shows the tools commonly used by masons.

Mason's Tools: Hammers and mallets.—1. The mallet is formed of a truncated cone of hard wood with handle, and is used for striking the mallet-headed chisels. 2. The dummy is similar in form, but with a smaller head, and generally used in carved work. 3. Iron hammer: This has a head similar to a carpenter's mallet, but made of iron; this is used for carved work. 4. The mash hammer: this has a heavy head and short handle, and is used upon the hammer-headed chisels. 5. The waller's hammer, used for roughly fitting stones in rubble work. 6. The pick: this has a long head, pointed at both ends, and weighs about 16 lb.; used for roughly dressing granite and also for splitting other stones in the quarry. 7. The axe has a head shaped like a double wedge, and of about 12 lb. in weight,



Figs. 316–356. Mason's Tools.

used for forming a labour, similar to tooled work upon granite. 8. Patent axe: this is also used for fine axed granite work, and consists of a number of plates bolted together in a head formed specially. 9. Spalling hammer, used for roughly dressing stones in the quarry. 10. Scabbling hammer, has one end pick-pointed, and is used for roughly dressing hard stones in the quarry.

Setting out and setting tools. 1. The square, formed of iron, each arm being about 18 inches long. 2. The set square formed of iron, set to 45 degrees or other angles as required. 3. The bevil, formed of two blades of iron slotted and fastened with a thumbscrew. 4. The spirit level, which should be at least 18 inches long. 5. Compass for dividing. 6. The rule. 7. The plumb rule and bob for testing verticality. 8. The trowel for spreading mortar.

Cutting Tools.—Chisels are divided into two classes—those for use with the hammer, and those for use with the mallet. The hammer-headed chisels have the section of their striking end made smaller, to lessen the amount of burr. The mallet-headed chisels have their striking ends made broader to avoid injuring the mallet. 1. The punch has a cutting edge about a $\frac{1}{4}$ inch long, it is used with the hammer for removing superfluous stone in roughly dressing. 2. The point has an edge similar to that of the punch, but is used with the mallet for hard stones. Hammer and mallet-headed chisels are made with lengths of edges from $\frac{1}{4}$ inch to $1\frac{1}{4}$ inches wide; mallet-headed chisels from $1\frac{1}{2}$ inches edge upwards are termed boasters for tooling surfaces. The claw tool has an edge with a number of teeth from $\frac{1}{8}$ inch to $\frac{3}{8}$ inch in width, and is used for dressing surfaces of hard stones after the point or punch has been used. The pitching tool has a long cutting edge which has a large internal angle and is used with the hammer for reducing stones. Jumpers are used for boring holes in quarrying granite, or for blasting operations; they are of varying lengths,

and have their edges in length greater than the diameter of the tool, so that they may leave a clearance and permit of the tool being turned round in the hole being bored. The wood-handled chisel, similar to a carpenter's firmer chisel, is used upon Bath and other soft stones. The drag is a piece of steel plate with an edge cut similar to a saw tooth and is used for bringing or dragging the surfaces of soft stones to a uniform level. Cockscombs are specially shaped drags for moulded work in soft stones. The wedge and feathers, used generally for splitting granite, consists of a conical wedge and two thin curved plates; these are placed in a series of holes made by a jumper along a required line of section for severing the stone. Gads are small iron wedges used for splitting softer stones; these are inserted in chases made by the pick.

Saws Worked by Hand.—1. The hand saw, 28 inches in length, used for cutting soft stones, is similar to a carpenter's half rip saw. 2. The double-handed saw, to be worked by two men, from 5 to 6 feet in length. 3. The frame saw, used for cutting large blocks of stone, consists of a frame as shown in figure, the weight of which is supported by being slung on to a system of pulleys arranged to give the saw the required amount of vertical play. The blade of this saw consists of a piece of steel about $\frac{1}{10}$ inch in thickness and 4 inches in width, and is fixed to the frame by means of two steel pins. The cutting action is assisted by coarse sand and water, which is allowed to dribble into the cut from a tinware vessel placed conveniently by the side of the work. The saw should be about 2 feet 6 inches longer than the stone to be cut; for this purpose blades and stretchers of varying lengths are kept, and the coupling irons at the top may be increased in length by the addition of loose links.

Hoisting Apparatus.—1. The nippers consist of two curved and pointed arms rotating on a pivot, and fitting into notches cut on the sides of the stone; the tendency is

to bite more tightly as it is lifted. These are convenient for manipulating stones too large to be easily handled. It is necessary where stones are too large to be easily lifted that they should be placed exactly in their position by the lifting apparatus, to avoid disturbing the green work underneath. For this purpose lewises, which are arrangements of dovetailed shaped blocks, are let into a special hole cut into the top bed. Four varieties are shown in the plate. 2. The scaffold jib, as shown in figure, is employed where a derrick or other crane is not used, and where the stones are first raised on the scaffold, and from there manipulated to their bed; it consists of two timbers, about 9 in. or 11 in. by 3 in., according to the weight to be lifted, bolted together at their ends, and leaving a space of about 4 inches between the timbers; it is supported by the ledgers of the inside and outside scaffolds at a convenient height above the work; it is supplied with an iron roller of about $1\frac{1}{2}$ inches diameter with four arms at each end, the chain supporting the pulleys is passed over the roller, and the stone when raised can be moved in a transverse direction by turning the levers of the roller.

Specification of Mason's Work (Edinburgh School Board).—The following may be taken as a typical specification in a stone district:—

Excavations.—The whole of the surface soil for 12 inches deep to be excavated under the site of the building and carted away to a place of deposit to be found by the contractor.

Tracks.—The tracks of all walls to be excavated to the sizes shown on plan, or 15 inches wider than thickness of walls and in depth until a solid foundation is obtained, the surplus after what is required to fill in around walls to be carted away.

Foundations.—The foundation course to be of hard solid, flat bedded stones, hammer dressed on beds and squared on

joints laid solid in lime mortar 8 inches thick, and full breadth of wall in single stones, each stone to be at least 12 superficial feet.

The foundations for partitions and the inner walls to be as already specified only 6 inches thick, but every stone across wall in one stone, and at least from 2 to 3 feet long.

Rubble.—The walls to be built of good sound rubble stones from a quarry approved of by the architect in writing before the work is begun, the main stone walls to be 2 feet 6 inches thick up to underside of sleeper joists, and 2 feet above them.

The partition walls to be 15 inches thick up to level of sleeper joists, and sleeper walls to be 12 inches thick, all built and bonded throughout with headers in every course not more than 5 feet apart. The walls to be carried up not more than 12 inches to 15 inches at a time, the whole to be levelled at underside of sleeper joists for asphalte.

Asphalte.—Damp courses to all walls $\frac{1}{2}$ inch thick, composed of best British pitch, Stockholm tar, and washed kiln-dried gravel, spread on walls while hot without cracks, and built on immediately after laying to prevent breaking; the internal walls to be covered with boarding to prevent being destroyed until they are to be built on. The whole area of building under wood floors to be levelled up with stone shivers to about 12 inches under sleeper joists, hard beaten down and rammed all round walls, the stone coating to be at least 6 inches thick. The whole to be covered over with a $\frac{3}{4}$ inch coat of asphalte as previously described free from cracks. This will be done after the building is up, and when the joiners are preparing to lay the floors on top of same to prevent it being destroyed.

External Face Snecked Rubble.—The external face of walls to be built of split-faced or natural-faced rubble work having no tool marks on the face, squared on the joints and beds with mallet and chisel, the full thickness of stone,

which are not to be less than 8 inches thick, having headers at least not more than 5 feet apart. These stones are to be none higher than 8 inches nor less than 3 inches, nor more than three times their height in length nor less than twice their height, nor must more than three heads come together. The joints and beds to be $\frac{1}{2}$ inch, and neatly set to this; the building mortar to be kept back $1\frac{1}{4}$ inches from face for pointing afterwards.

Pointing.—The face of this wall to be pointed with cement and sand after the building is completed, the proportion being three of sharp sand to one of best Portland cement, properly mixed on a board, the beds and joints being well damped before this mortar is used, and to be pressed in with a $\frac{3}{8}$ inch iron key, hard and sunk in, as shown in Figure 146*e*.

Inside of Walls.—The insides of these walls are to be built with good level bedded stones built cross bond throughout, and backed up to outside face every 15 or 18 inches in height, and grouted up with lime grout every time they are levelled.

Scontions.—The scontions at inside angles or outside corners under ground level to be of large-sized stones, say 20 inches long, 12 inches thick, and of heights to suit outside hewn work at openings where they connect. Scribbled on beds and faces wrought to the shapes required, including bay on sides of windows, and properly bonded with rubble walls.

Hewn Work: Corners.—The corners to be of sandstone from Prudham Quarry of the best liver rock, average length 20 inches, thickness 10 inches, to vary, but these to average in height from 8 inches to 12 inches squared and chiselled on beds and joints, and finely scabbled or tooled on face. Diagonally to have seven tool marks to every inch, set in fine lime and pointed with cement mortar when the rest of walls are being pointed. The beds to be $\frac{3}{16}$ inch thick.

Window Sills.—The window sills to be of same stone as corners, 14 inches broad and 9 inches thick, scabbled as corners, on exposed surface, weathered and throated and reprized for rybats having 9 inches longer on each end than daylight of windows.

Rybats.—The rybats of windows to be same stone as for corners, and scabbled as specified for corners. The inbans in 2 feet walls to go right through the walls, and to be 12 inches on heads checked for window cases and moulded on angle. The outbans to average 20 inches long and 10 inches on heads checked for window cases, and moulded on angle, the moulding average 8 inches girth. The height of the rybats to average 8 inches to 12 inches in various heights, set in fine lime and pointed with cement mortar along with the rest of the walls.

Lintels.—The lintels of outside openings to be same stones as corners, and scabbled same on exposed parts, to be 9 inches longer on each end than daylight of opening, 14 inches high and 12 inches thick, checked for window case on inside angle and moulded, and reprized to suit rybats on outside angle, set in fine lime and pointed as before.

Mullions.—These stones, same as before, in single lengths and 7 in. × 7 in., moulded same as rybats on two angles, dowelled with slate dowels 2 in. × 1 in. to sills and lintels.

Saves.—The lintels over all voids to be saved with long rubble stones meeting in centre, or joined with a key stone between; these saves to be broad on beds and of heights to match face work chiselled on beds and joints, and same as face work on face.

Arches.—The inside of window openings to be arched with 9 inches brick arch set in cement, having stone springers shaped to the proper radius; in case of wide windows the inside to be lintelled over with two rolled

steel joists, 8 in. × 6 in., covered on top with flat stones 5 inches or 6 inches thick, and full breadth from inside face of wall to back of outside lintel, close jointed.

Base Course.—The base course of same stone as corners, and scabbled where exposed, 14 inches broad and 9 inches high, splayed on angle and tooled, squared on joints close set and pointed as before.

String Course.—To be 14 in. × 6 in. moulded on projection and tooled; girth of tooled work 12 inches weathered on top 4 inches.

Skews.—The skews to be 18 in. × 6 in., tooled where exposed, and moulded on edge and plain on inside, bedded and pointed with cement.

Skew Puts.—These to be about 30 in. long by 18 in. broad and 15 in. high, moulded and sunk on face to match skews, also on end for return, and sunk on top bed.

Ties.—In centre of height of skews, tie stones about 2 feet long and 14 inches high, sunk on face with skews relieved.

Apex.—The apex stones to be about 2 ft. × 2 ft. × 18 in. having skews relieved on their face, sunk and scabbled, the backs sunk for slates.

Chimney Cope.—The chimneys to have moulded cope, each stone the full breadth scabbled all round 12 inches thick, with holes for vents cut through the solid 10 inches diameter, and batted with iron bats at joints, sunk below flush, filled in and covered with cement.

Cans.—Red chimney cans 2 feet 6 inches high, moulded and tapered, sunk 2 inches to cope, and filleted all round with cement.

CHAPTER VI.

WALLS.

Walls.—Walls made with bricks are practically fences, generally vertical, and enclose areas or support earth or water. They consist of base, body, and cornice or coping. The base is usually extended in a transverse direction either by battering or by offsets, technically known as footings, to distribute the pressure of the wall above over an area sufficiently great to carry the load. Damp is prevented from rising from the ground up walls by a horizontal course of damp-resisting material, which must be placed at a height sufficient to prevent a driving rain splashing up and wetting the wall above the damp course, and as low as possible to reduce to a minimum the amount of the wall wetted by capillary attraction; usually a distance of 6 inches or not more than 1 foot above the ground level is found to be most suitable. Water is prevented from passing down from the top of walls by a damp-proof course which may consist of a stone coping weathered sufficiently to throw off all water rapidly, and with a cornice the purpose of which is to throw all water coming upon it as far as possible from the body and base of the wall.

Wall Classification—

1. Walls of uniform thickness.
2. Walls buttressed and with curtain walls.
3. Retaining walls.

1. Walls of uniform thickness, solid and hollow as shown in Figures 357 to 362. These are employed where the weights from floors, roofs, etc., to be supported are evenly distributed over the length of the wall. The space in a hollow wall is arranged for the further purpose of rendering the temperature within the building less subject to variations, and also to prevent damp passing through from the exposed face. The two walls are connected together with stoneware or iron ties, as shown in Figures 360 to 362 spaced as shown in Figure 359.

2. The buttressed and with curtain walls. These are of two kinds (*a*) where the loads to be supported are concentrated at points as from the trusses of roofs, in which case it is unnecessary to have the walls of uniform thickness throughout the length, buttresses being constructed to resist the thrusts of trusses, and comparatively thin walls being built to connect the buttresses to complete the enclosure as shown in Figures 363 to 365; (*b*) where the weights from floors are concentrated at intervals by means of girders as in double floors. It is necessary only to have piers of a horizontal area sufficient to resist the superincumbent pressures, these being connected by thin curtain walls as shown in Figures 366 to 368. As in these cases the weights are concentrated at intervals on the foundations, it is frequently necessary to connect the piers near their bases with inverted arches to distribute the pressures equally over the whole of the foundation as shown in Figure 366, and fully dealt with in the chapter on "Foundations."

3. These include retaining walls or revetment walls and dams. Revetment walls are designed to support masses of earth, as in cuttings, as shown in Figures 369 to 371. These may be constructed (*a*) with a vertical face; (*b*) with a straight batter; (*c*) with a curved batter; generally for similar embankments most wall material is required for method (*a*), and the minimum quantity for method (*c*); those

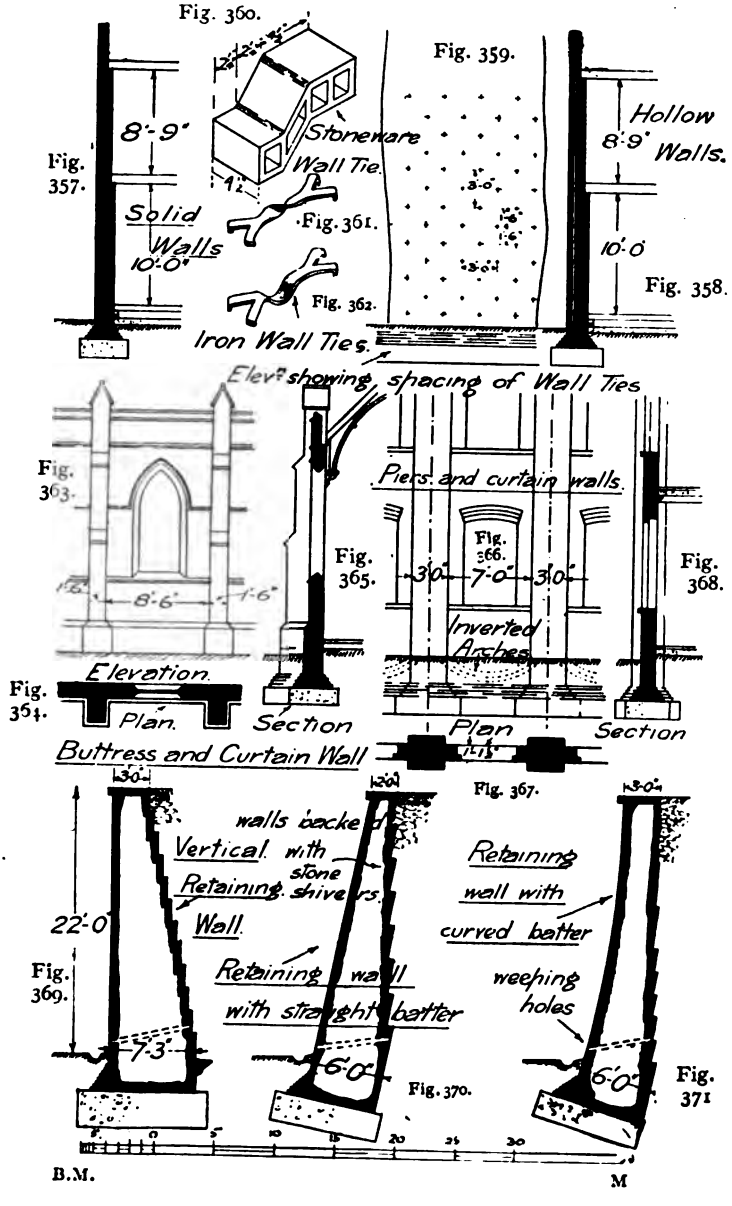


Fig. 360.
Fig. 359.
8'-9"
Stoneware
Wall Tie.
Hollow
8'-9"
Walls.
Fig. 357.
Solid
Walls
10'-0"
Fig. 361.
10'-0
Fig. 358.
Fig. 362.
Iron Wall Ties.
Elevt showing spacing of Wall Ties
Fig. 363.
Piers and curtain walls.
Fig. 366.
Fig. 365.
Fig. 368.
3'-0"
7'-0"
3'-0"
8'-6"
1'-6"
Inverted
Arches
Elevation.
Fig. 364.
Plan.
Section
Plan
Section
Buttress and Curtain Wall
Fig. 367.
walls backed
Vertical with
stone
Retaining shivers.
Wall.
Retaining
wall with
curved batter
22'-0
Fig. 369.
Retaining wall
with straight batter
weeping
holes
7'-3"
6'-0"
Fig. 370.
6'-0"
Fig. 371
B.M.
M

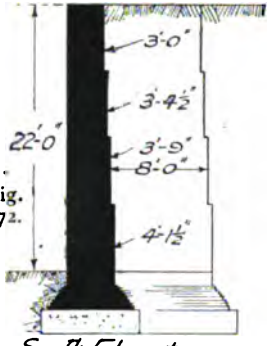


Fig. 372.

Sec^n. Elevation

Retaining Wall with Counterforts behind

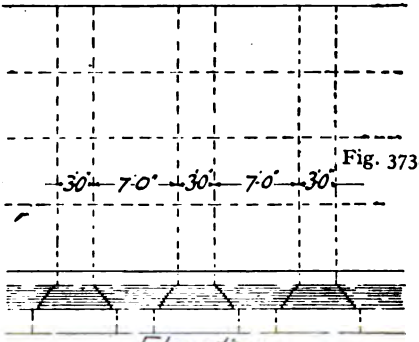


Fig. 373.

Elevation

Fig. 374.

Plan

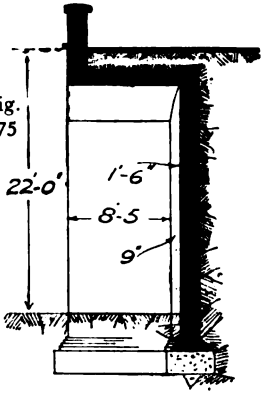


Fig. 375

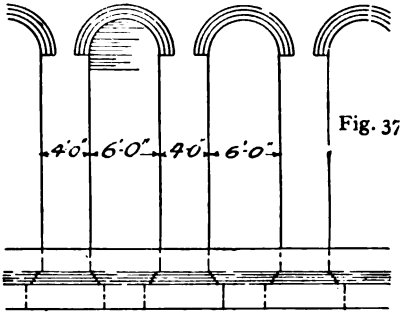


Fig. 376.

Horizontal Arches and Buttresses

Fig. 377.

designed only to protect the face of a cutting, the strata of the earth on the sides of which are inclined away from the cutting and in a downward direction, not therefore being liable to fall *en masse*, but only to decompose and fret away under the action of the atmosphere, are known as breast walls. High retaining walls are frequently constructed (1) with counterforts behind, as shown in Figures 372 to 374; (2) as a series of horizontal arches with heavy abutments in front. It is usual to arch over the spaces between the abutments, as shown in Figures 375 to 377, or (3) the earth may be maintained by a series of relieving arches into the spaces, beneath which the earth is allowed to assume its natural slope, a thin wall usually being built in front of the relieving arches to present a fair face, as is shown in Figures 378 and 379. Dams are retaining walls constructed to resist the pressure of water.

STABILITY OF WALLS.

The following will apply to walls classified (*a*) and (*b*):—

Walls made of such materials as brick or stone may be supposed, for the purposes of calculation, to be composed of (*a*) uncemented blocks, or (*b*) cemented blocks. Walls may be satisfactorily considered as built of uncemented blocks, when the force disturbing its equilibrium acts before the bedding or joining substance has had time to set, that is, obtains an adhesion and tenacity equal in strength to the materials which are held together, or possesses sufficient of those two resisting powers to withstand the disturbing force. Hence it follows that walls, such as chimney stacks, chimney shafts, buttresses, etc., work where the failure of one joint would be disastrous, work that cannot be or is not strutted, nor otherwise supported, and will probably have to resist a disturbing element such as wind force

before the bedding material has had time to set; such walls should be calculated as if made of uncemented blocks.

Minimum Thickness.—The thickness of walls of dwelling-houses and warehouses has been determined by vast experience, and the minimum thickness is given later in this chapter, and no advantage would therefore be derived from calculating them, although it would be more satisfactory if a dangerous wall were more sharply defined; as the practice given by an eminent authority in these

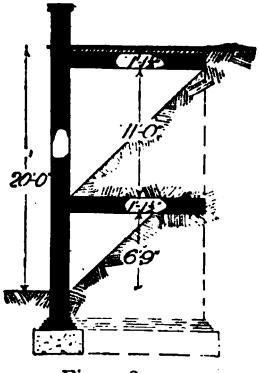


Fig. 378.

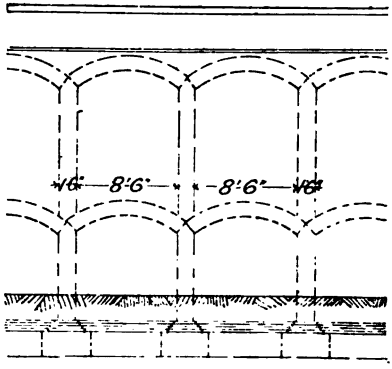


Fig. 379.

Relieving Arches.

matters, that he should consider a wall overhanging one in twenty-four not unsafe, and dangerous when it overhangs one in twelve, although useful as a guide, for which purpose it was given, can scarcely be considered a final and satisfactory conclusion.

Fence or boundary walls are usually calculated as built up with a number of cemented blocks—that is, the strength of the mortar is considered, for it may be easily shown that the thickness of the majority of fence walls would be insufficient, were it otherwise, to resist the wind pressures frequently attained.

Classification of Failures.—A wall consisting of uncemented blocks (that is, supposing mortar to be used, its tenacity and adhesion being neglected) may fail from the following causes:—(*a*) By the overturning of some one or more blocks on their edges; (*b*) by crushing if the pressure be great enough and distributed over too small a surface; (*c*) by the sliding of some one or more of the blocks on their bed joints.

Overturning.—Consider proposition (*a*). If the wind pressure is to be considered as the external disturbing force, multiply the superficial area of wall face by the wind pressure (P), and by its leverage, which is equal to one-half of the height of the wall, the product will be the value of the moment of the disturbing element. Therefore, the moment of the wind pressure or its power to overturn the wall may be represented by the formula, exposed surface $\times$ P $\times$ leverage, which in an ordinary wall with rectangular faces would give $(h \times l) \times (P) \times (h \div 2)$, when P = pressure of wind in lbs. per square foot, l = length of wall usually in feet, h = height of wall usually in feet against a surface perpendicular to its direction.

Assuming that the strength of the materials and the accuracy of the bonding is uniform throughout a wall, its power to resist external forces, neglecting strength of mortar, will depend upon the leverage of external forces as compared with the leverage of the mass or weight of the wall acting at its centre of gravity. One edge of the wall at its base may be considered as a fulcrum; the weight of the wall acts with a leverage equal to one-half the thickness of the wall. Therefore, the moment of the mass of the wall, or its power to resist external forces may be represented by the formula, cubic content $\times$ W $\times$ leverage, which in an ordinary wall of the rectangular prismatic type might be stated as $(l \times t \times h) \times (W) \times (t \div 2)$, when t = thickness of wall (usually in feet), W =

weight (usually in lbs.) per foot cube of wall material, other symbols as stated previously. When the moment of the wind pressure equals the moment of the mass of the wall, the structure is on the brink of overturning, the pathway of the centre of pressure passing through the centre of gravity of the wall, and that edge of the wall which is acting as the fulcrum under these conditions may be described as in unstable equilibrium. The equation for walls in unstable equilibrium of the usual form may be stated thus:—

Moment of wind pressure = Moment of mass of wall.

$$(l \times h) \times (P) \times (h \div 2) = (l \times t \times h) \times (W) \times (t \div 2).$$

It is sufficient for the purposes of calculation to consider a portion of the wall 1 foot in length as that factor appears on both sides of the equation.

The following is a table giving the velocity and pressure of winds, or the value of P.

TABLE SHOWING THE VELOCITY AND PRESSURE OF WINDS.

Designation.	V = Velocity in miles per hour.	P = Pressure in lbs. per square foot.
Scarcely perceptible	1	·005
Perceptible	2	·020
Slight breeze	4	·080
Moderate ,, ...	8	·320
Fresh ,, ...	15	1·125
Brisk wind	25	3·125
Strong ,, ...	30	4·50
High ,, ...	40	8·00
Storm	50	12·50
Violent storm	60	18·00
Hurricane	80	32·00
Violent hurricane	100	50·00
Gust observed in England in 1865 ...	126	80·00

Let P = pressure of wind in lbs. per square foot against a surface perpendicular to its direction.

If the velocity in miles per hour is known, the value of P may be deduced from the empirical formula $P = V^2 \div 200$, or if P is given, $V = \sqrt{200\,P}$.

Crushing.—Consider the walls for safety from crushing, as the equation already stated only satisfies proposition (*a*), and represents unstable equilibrium on the brink of overturning. This condition of safety is usually fulfilled by making the wall of sufficient thickness to meet the require-

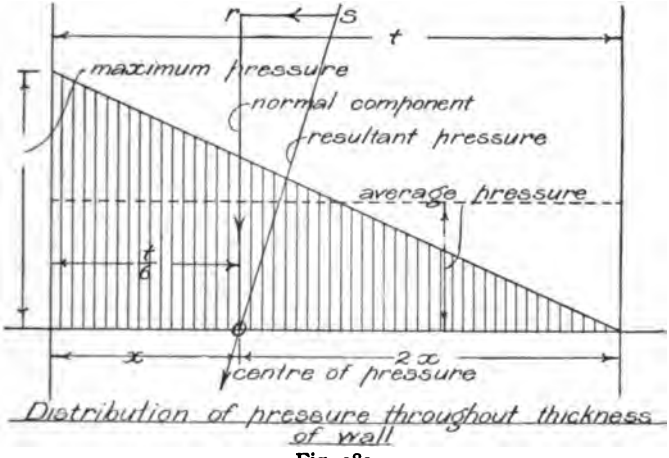


Fig. 380.

ments of proposition (*b*), which is complied with when the centre of pressure falls sufficiently within the walls for the section of the wall to resist crushing where the stress is at its maximum, which in a wall of ordinary section is at the ground line and on its outer edge.

Where the resultant of wall and overturning pressures intersects a base or bed joint of a wall, at a distance of one-third or less of the thickness of the wall from the outer edge, the section under compression will be three times that distance,

Taking for example a wall the centre of pressure of which is one-third of its thickness from its outer edge, the pressures are found to vary as the ordinates of a triangle, the maximum pressure being on the overturning edge, to zero on the inner edge of wall. The value of the pressure on the overturning edge will be twice the average pressure on the compressed section of the base, as shown in Figure 380.

The section under compression will be stressed to the value of the component normal to the bed joint, of the resultant pressure.

Therefore for calculations, taking a unit length of wall, determine—

(1.) The distance of the centre of pressure from outer edge;

(2.) Multiply by three this distance, if the latter is a third or less of the thickness of the bed joint, this product into a unit length will be the compressed area;

(3.) The value of the normal component divided by this area will equal the average pressure per unit of area.

(4.) Twice the average pressure will be the maximum pressure on the outer edge, and which should not exceed the safe resistance of the material.

The units usually taken are inches and lbs.

It is useful to know the limiting position of the centre of pressure often adopted, which for ordinary building materials satisfies proposition (*b*); this is given in the following table.

Limiting Position of the Centre of Pressure.
(*Rankine.*)

If a line in the direction of the force be drawn through the centre of gravity of base, then let

A = the point where line intersects side not exposed to the force.

B = the point where line intersects side which is exposed to the force.

C = the extreme position of the centre of pressure.

Figure of base, or bed joint under consideration.	Distance from outside edge.
Rectangle solid	A C = $\frac{1}{6}$ A B
Square solid	A C = $\frac{1}{6}$ A B
Ellipse solid	A C = $\frac{3}{8}$ A B
Circle solid	A C = $\frac{3}{8}$ A B
Hollow square (factory chimneys) ...	A C = $\frac{1}{8}$ A B
Circular ring (factory chimneys)	A C = $\frac{1}{4}$ A B

Example:—A chimney stalk rises 20 feet clear of roof; find thickness required to resist wind pressure of 56 lbs. per square foot, neglecting the resistance of the mortar. Assume the chimney stalk to weigh 60 lbs. per foot cube on an average.

For calculation, take a length of one foot of wind pressure and chimney.

The equation for equilibrium or on the brink of overturning is, as already stated, as follows:—

Moment of wind pressure = Moment of weight of chimney

$$P \times h \times l \times \frac{h}{2} = w \times h \times l \times t \times \frac{t}{2}$$

The limiting position of the centre of pressure, as may be seen from number five line of the given table, is one-sixth of the required thickness from the lee side, therefore the perpendicular distance from the centre of gravity of the wall to the limiting position of the centre of pressure, will be the thickness over three. This will satisfy (*a*) and (*b*) conditions for safety, whilst (*c*) proposition may easily be tested for safety by drawing the diagram of resultant pressure and bed joints, and noting whether it satisfies

the rules given in the following paragraph on Sliding. Therefore the equation for safety becomes—

$$\text{Moment of wind pressure} = \text{Moment of weight of chimney}$$

$$P \times h \times l \times \frac{h}{2} = w \times (h \times l \times t) \times \frac{t}{2}$$

$$56 \times 20 \times 1 \times 10 = 60\,(20 \times 1 \times t) \times \frac{t}{2}$$

$$11200 = 400\,t^2$$

$$t^2 = 11200 \div 400$$

$$t^2 = 28$$

$$t = \sqrt{28} \text{ or } 5{\cdot}3 \text{ ft. nearly.}$$

Example:—What wind force per foot super would overturn a 14-inch brick wall 10 feet high and weighing 108 lbs. per foot cube, neglecting the strength of the mortar?—*Science Exam. Honours.*

$$\text{Moment of wind pressure} = \text{Moment of mass of wall.}$$

$$P \times h \times \frac{h}{2} = w \times h \times t \times \frac{t}{2}$$

$$P \times 10 \times 5 = 108 \times 10 \times 1{\cdot}16 \times {\cdot}58$$

$$50\,P = 726{\cdot}624$$

$$P = 14{\cdot}532 \text{ lbs.}$$

Sliding.—The stability of walls with respect to proposition (*c*) or sliding will now be considered. If a rough plane with a body upon it be gradually tilted, there is a certain angle to the horizontal when sliding is about to take place. This angle is known as the "angle of repose," and the ratio of the height of such a plane to its base is known as the co-efficient of friction. The angle of repose has been determined experimentally for a number of materials. It is not difficult to draw the resultant pressure and note the angle which it makes with the normal to the bed joints. The direction of the resultant pressure must not make a greater angle with the normal to bed joint than the angle of repose. For safety it is usual not to let the angle which the direction of the resultant pressure makes with the normal to the bed joint exceed the angle of which

0·8 of the co-efficient of friction of the material is the tangent.

GENERAL MORIN'S TABLES.

Surfaces.	Angle of Repose.	Co-efficient of Friction.
Dry masonry and brickwork	31° to 35°	0·6 to 0·7
Masonry and brickwork with wet mortar ...	25½°	0·47
Masonry and brickwork with slightly damp mortar	36½°	0·74
Wood on stone	22°	0·4
Iron on stone	16⅔° to 35°	0·3 to 0·7
Masonry on dry clay	27°	0·51
Masonry on moist clay	18¼°	0·33
Earth on earth	14° to 45°	0·25 to 1·0
Earth on dry sand, clay, and mixed earth ...	21° to 37°	0·38 to 0·75
Earth on damp clay	45°	1·0
Earth on wet clay	17°	0·31
Earth on shingle and gravel	35° to 48°	0·7 to 1·11

Side Thrusts.—The overturning pressures from rafters, vaults or similar forces upon walls may be calculated as follows:—

Example:—A rectangular wall, 10 feet high, has to resist a thrust of 500 lbs. per foot run applied at an angle of 60 degrees to the horizon at a height of 8 feet above the ground level.

Taking the weight of the wall at 100 lbs. per foot cube, what must be its thickness, supposing it to be unstable without taking into consideration the strength of the mortar?

Let a length of 1 foot be taken.

500 lbs. at 60 degrees to the horizon will give a horizontal component of 250 lbs. and a vertical component of 433 lbs. The point of application is 8 feet high on the thrust side. Let the force be here resolved into its horizontal and vertical components, then for unstable equilibrium—

$$\left.\begin{array}{r}\text{Moment of horizontal com-}\\ \text{ponent of pressure}\end{array}\right\} = \left\{\begin{array}{l}\text{Moment of vertical component}\\ \text{of pressure + moment of}\\ \text{mass of wall}\end{array}\right.$$

$$250 \times 8 \times l = (433 \times t) + (h \times t \times l \times w)\,\frac{t}{2}$$

Let a length of 1 foot be taken, then—

$$2000 = (433\,t) + (10 \times t \times 1 \times 100)\,\frac{t}{2}$$

$$2000 = 433\,t + 1000\,\frac{t^2}{2}$$

$$500\,t^2 + 433\,t = 2000$$

$$t^2 + \frac{433}{500}\,t = 4$$

$$t^2 + \frac{433}{500}\,t + \left(\frac{433}{1000}\right)^2 = 4 + \left(\frac{433}{1000}\right)^2$$

$$t + \frac{433}{1000} = \pm\,2{\cdot}046$$

$$t = 2{\cdot}046 - {\cdot}433$$

$$t = 1{\cdot}613 \text{ feet}$$

This problem could be worked with the same result by imagining the force continued till it intersected the vertical passing through the centre of gravity of the wall. The statement would then be—

$$\left.\begin{array}{l}\text{Moment of horizontal com-}\\ \text{ponent of pressure}\end{array}\right\} = \left\{\begin{array}{l}\text{Moment of vertical component}\\ \text{of pressure + moment of}\\ \text{mass of wall}\end{array}\right.$$

$$250\left(8 - \frac{\sqrt{3}}{2}\,t\right) = \left(433\,\frac{t}{2}\right) + \left(h \times t \times l \times w\right)\frac{t}{2}$$

The following table, compiled from Wray and Rankine, will be found useful:—

STRENGTH OF MORTAR.

	Tension. lbs. per sq. in.	Adhesion. lbs. per sq. in.
Mortar composed of one part of Portland cement to two of sand (after a very short time)...	280	280
Do., one part blue lias lime to two of sand with hard grey stocks	140*	36†
Do., do., with place bricks	—	18†

Mortar made with weak hydraulic lime, or pure lime and sand, possesses such a small amount of strength that practically it may be neglected.

* After 7 days. † After 6 months.

In ascertaining the strength of walls on this principle, only the lowest value of the mortar (whether tension or adhesion to brickwork) should be taken.

For practical purposes it may be considered that after allowing time for setting—say, from three to six months, according to the value of the mortar—good stock brickwork will begin to fail by cracking at a pressure of 200, 400 or 700 lbs. per square inch, according as it is laid in grey chalk lime, lias lime or Portland cement mortar; for ultimate crushing from one and a half to twice these pressures would be required.

Structures with Cemented Blocks.

The following method of calculation is rarely used in the case of chimneys and shafts, nor is it applicable for structures having a great number of joints; it is used chiefly for enclosure walls, short projections, and works of minor importance.

Wind pressure is the principal disturbing force acting on walls, and those joints which have to withstand the greatest stress are at the lowest position, where the wind exerts the greatest turning moment.

If the wall be of uniform section throughout, it is quite sufficient if the strength of the lowest joint be calculated; but if the thickness be variable, the lowest joint at each change of section must be taken.

It follows from the above, that since there is less stress on the joints in the upper portion, in many cases a wall might very well be built in lime mortar with only the joints in the lowest portion made with cement mortar.

In addition to external forces there is an internal compressive force due to the weight of the mass of the wall itself. Under certain conditions, however, as in some retaining walls where the joints are not horizontal, this

force may cause a portion of the joint to be subjected to a shearing stress, though the strength of mortar and the resistance due to friction are always more than sufficient to withstand that force.

To ascertain the pressure of the wall on the joints, divide the weight of the wall in pounds by the horizontal sectional area in inches, and the result will be the pressure in pounds per square inch—

Let A be the windward side of the wall.
,, B ,, leeward ,, ,,
,, M ,, pressure of the wall at A.
,, N ,, ,, ,, ,, B.

In ordinary cases M and N are equal. The moment of resistance would equal the strength in tension or compression, and be symbolised by (fo).

Hence the pressure at A = M + ft. (The algebraical sum.)

Hence the pressure at B = N + fc.

From the foregoing, it will be seen that the strength of the wall may be represented by the following equation :—

$$\left.\begin{array}{l}\text{Moment of wind pressure} + \\ \text{pressure on joint}\end{array}\right\} = \left\{\begin{array}{l}\text{Moment of resistance of the} \\ \text{joint.}\end{array}\right.$$

The "moment of wind pressure" is the pressure (P) multiplied by the area on which it acts ($h \times l$) multiplied by the leverage $\left(\frac{h}{2}\right)$; and the "moment of resistance" of the joint is the strength in tension or compression multiplied by the moment of inertia (I) divided by the tendency to break (δ). The moment of inertia has been shown to be in rectangular bodies the breadth multiplied by the cube of the depth divided by 12, and the tendency to break is the mean distance of the particles from the neutral axis, or half the depth. For present purposes let us consider the wall as a vertical cantilever, and in this case the thickness of the wall would be the depth (D).

The formula may be expressed symbolically thus:—

$$P \times (h \times l) \times \left(\frac{h}{2}\right) = \frac{fo \times I}{\delta}$$

The method of applying this will be shown by the working of the following example:—

Example:—A long enclosure wall 12 feet high, 2 bricks thick, set in hydraulic mortar and weighing 100 lbs. per cubic foot, built in an exposed position in a country where the wind has registered a pressure of 55 lbs. per square foot. Determine the compression on the lee side and the tension on the wind side.

$$P \times (h \times l) \times \frac{h}{2} = \frac{fo\ I}{\delta}$$

$$\frac{55}{1.4} \times 144 \times 12 \times \frac{144}{2} = \frac{fo \times \frac{bd^3}{12}}{\frac{d}{2}}$$

$$\frac{55 \times 144 \times 12 \times 144}{144 \times 2} = \frac{fo \times 12 \times 18^3 \times 2}{18 \times 12}$$

$$47520 = 648\ fo$$

$$fo = \frac{47520}{648}$$

$$fo = 73\cdot\dot{3}$$

The above being a wall rectangular in section, there would be an equal pressure from the wind on both sides, with this difference, that on the windward side is a tensional, and that on the leeward a compressional stress.

The pressure of the mass of the wall may be found thus:

$$W \times h \times t \times l = P$$

$$100 \times 12 \times 1\tfrac{1}{2} \times 1 = 1{,}800 \text{ lbs.}$$

$$\text{Area} = 18 \times 12 = 216 \text{ sq. ins.}$$

$$\therefore \frac{1800}{216} = 8\cdot\dot{3} \text{ lbs. per sq. in.}$$

Then pressure on windward side $= 73\cdot\dot{3} - 8\cdot\dot{3} = 65$ lbs. per square inch under tension.

Then pressure on leeward side $= 73\cdot\dot{3} + 8\cdot\dot{3} = 81\cdot\dot{6}$ lbs. per square inch under compression.

Under such circumstances a wall set in hydraulic lime mortar would be very liable to fail, and, in fact, could not be expected to stand such an adhesional or tensional stress; but, as brickwork set in hydraulic mortar will fail under a compression of 400 lbs. per square inch, the factor of safety

$$= \frac{400}{81\cdot\dot{6}} = 4\cdot9 \text{ nearly.}$$

Therefore, although it would be sufficiently strong to resist compression, it would fail by its adhesive and tensile resistance being insufficient, and the lower part, at least, of such wall would be wisely built in cement.

Thicknesses of Walls.—The thickness of external and party walls is required by the Model Bye-laws to be built in accordance with the following regulations:—In every case the thickness prescribed is the minimum thickness, and the regulations only apply to walls built of good bricks, not less than 9 inches long, or of suitable stone, or other blocks of hard and incombustible substances, the beds or courses being horizontal.

DWELLING-HOUSES.

Height up to 25 ft.	Length up to 30 ft. From base to top of wall 9 in.	Length unlimited. Wall below topmost storey 13½ in. Remainder 9 in.
Height up to 30 ft.		Length unlimited. Below topmost storey 13½ in. Remainder 9 in.
Height up to 40 ft.	Length up to 35 ft. Below topmost storey 13½ in. Remainder 9 in.	Length unlimited One storey 18 in. Rest of wall below topmost storey 13½ in. Remainder 9 in

DWELLING-HOUSES—*continued.*

Height up to 50 ft.	Length up to 30 ft. One storey 18 in. Rest of wall below topmost storey 13½ in. Remainder 9 in.	Length up to 45 ft. Two storeys 18 in. Remainder 13½ in.	Length unlimited. One storey 22 in One storey 18 in Remainder 13½ in.
Height up to 60 ft.	Length up to 45 ft. Two storeys 18 in. Remainder 13½ in.		Length unlimited. One storey 22 in. Two storeys 18 in. Remainder 13½ in.
Height up to 70 ft.	Length up to 45 ft. One storey 22 in. Two storeys 18 in. Remainder 13½ in.		Length unlimited. Wall to be increased 4½ in. in each of the storeys below the uppermost two storeys.
Height up to 80 ft.	Length up to 45 ft. One storey 22 in. Three storeys 18 in. Remainder 13½ in.		Length unlimited. Wall to be increased 4½ in. in each of the storeys below the uppermost two storeys.
Height up to 90 ft.	Length up to 45 ft. 26 in. one storey; 22 in. for the next storey. Three storeys 18 in. Remainder 13½ in.		Length unlimited. Wall to be increased 4½ in in each of the storeys below the uppermost two storeys.
Height up to 100 ft.	Length up to 45 ft. One storey 26 in.; 22 in. for two storeys. Three storeys 18 in. Remainder 13½ in.		Length unlimited. Wall to be increased 4½ in. in each of the storeys below the uppermost two storeys.

In the case of a wall exceeding 60 feet in height and 45 feet in length, or of a storey exceeding in height sixteen times the thickness prescribed

for its walls, or of a wall below that storey, the increased thickness may be confined to piers properly distributed, of which the collective widths amount to one fourth part of the length of the wall. The width of the piers may, however, be reduced, if the projection be proportionately increased so that the horizontal sectional area is not diminished, but the projection must in no case exceed one-third the width of the pier.

If any storey exceed in height sixteen times the thickness prescribed for its walls, the thickness of the external and party walls throughout that storey must be increased to one-sixteenth of the height, and the thickness of the external and party walls of the lower storeys shall be proportionately increased, subject to the above provision as to the use of piers. All external or party walls must be at least 13½ inches in thickness, if the storey exceed 10 feet in height.

Warehouse or Public Buildings Walls.

Height up to 25 ft.			Length unlimited. Base 13½ in.
Height up to 30 ft.		Length up to 45 ft. Base 13½ in.	Length unlimited. Base 18 in.
Height up to 40 ft.	Length up to 35 ft. Base 13½ in.	Length up to 45 ft. Base 18 in.	Length unlimited. Base 22 in.
Height up to 50 ft.	Length up to 30 ft. Base 18 in.	Length up to 45 ft. Base 22 in.	Length unlimited. Base 26 in.
Height up to 60 ft.		Length up to 45 ft. Base 22 in.	Length unlimited. Base 26 in.
Height up to 70 ft.		Length up to 45 ft. Base 22 in.	Length unlimited. Thickness from the base to within 16 ft. of top to be increased by 4½ in.
Height up to 80 ft.		Length up to 45 ft. Base 22 in.	Length unlimited. Ditto.
Height up to 90 ft.		Length up to 45 ft. Base 26 in.	Length unlimited. Ditto.
Height up to 100 ft.		Length up to 45 ft. Base 26 in.	Length unlimited. Ditto.

The thickness of these walls may be dealt with by the substitution of piers similarly as for dwelling-houses, except that the storeys must not

exceed in height fourteen times their thickness, and the collective width of the piers must be one-fourth the length of the wall.

A similar provision is also made as to thickness of walls, but in this case the thickness must be one-fourteenth the height of the storey instead of one-sixteenth as for dwelling-houses, and the least thickness for walls must be, as before, 13½ inches for storeys over 10 feet high.

The varying thicknesses of warehouse walls must be as follows:—

At the top, and for 16 feet below, it must be 13½ inches, and the parts between the base and 16 feet below the top must be built solid throughout the space between straight lines drawn on each side of the wall, and joining the thickness at the base to the thickness at 16 feet below the top. In walls not exceeding 30 feet in height, the walls of the topmost storey may be 9 inches thick if the height does not exceed 10 feet.

Cross walls, which may be deemed return walls for determining the length of external or party walls, shall be of two-thirds the minimum thickness prescribed for similar external or party walls, provided they are built of bricks or other suitable materials, as before described, but must in no case be less than 9 inches thick. If, however, such cross wall support a superincumbent external wall, the whole of the cross wall must be of the same thickness as an external wall of similar length and height for the same class of building.

Walls not built of the materials previously specified, must be built with a greater thickness, as follows:—

If built with clunches of bricks or other burnt or vitrified material, or of flint work (the beds or courses not being horizontal), the thickness must be one-third greater than for walls of a similar height, length, and class when built of brick.

If built of other suitable material, or of a combination of brickwork and flintwork in which the brickwork is equal to one-fifth of the entire cubic content of the wall, and is properly distributed in piers and horizontal courses, or of half-timber work, it may be of the thickness prescribed for a wall built of bricks, and shall be otherwise similar to walls of the same height, length, and class.

RETAINING WALLS.

Definition.—Walls built to retain masses of water or earth are known as retaining walls, and are classified as follows:—Those made to support (1) the pressure of water, are termed dams; (2) to keep in safe equilibrium masses of

earth, thus preventing sliding action, are known as revetment walls. A breast wall is a particular kind of revetment wall, constructed simply to protect from the weather a freshly exposed surface of a cutting, when the latter is such as to be capable of standing by itself if protected from the weather.

Conditions of Stability.—All retaining walls must satisfy

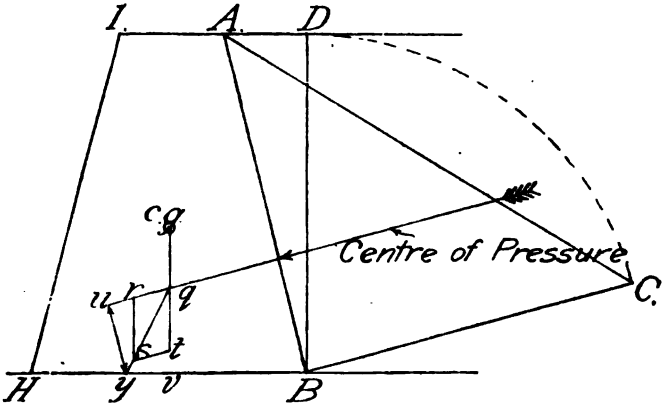


Fig. 381.

the three conditions given previously for the stability of walls in uncemented blocks.

Dams.

Pressure of Fluids.—The laws of fluid pressure state that the pressure at any part is directly as the height of a vertical column of water above that part, and is perpendicular to the surface pressed against. Thus, against any surface as *A B*, in Figure 381, the intensity of pressure varies from zero at *A* to the height of the vertical column of fluid upon *B*, and the total pressure for a unit of length

is the weight of the triangular prism of water, of which *A B C* is the section.

Against a sloping line in a vertical plane, containing *A B C* as *A B*, Figure 381, the pressure varies, as the ordinates between *A B* and *A C* from *A* to *C;* the maximum pressure at *B* being equal to the vertical column of the fluid directly above. Let *B C* be constructed at right angles to *A B*, and equal to *B D;* then the pressure for a unit of length is the weight of the triangular prism of water of which *A B C* is the section. In the diagram *q r* represents the pressure of the water, and *q t* the weight of the wall.

The line of the centre of pressure will pass through the centre of gravity of the triangular prism, and the direction of the pressure is normal to the surface pressed against, as shown in Figure 381.

REVETMENT WALLS.

Design.—In designing revetment walls it is necessary to determine (1) the plane of rupture; (2) the maximum horizontal thrust; and, after which, it is simplest to assume dimensions, then test same as to the necessary conditions of stability.

Proposition for Stability.—The calculations for stability of all revetment walls are based upon the following proposition:—The moment of the effective mass of wall acting vertically at its centre of gravity, multiplied by the perpendicular distance from the intersection of the resultant pressure and base (let this be named *y*) equals the horizontal component of sliding pressure of earth, multiplied by the perpendicular distance from *y*, this latter value is equal in cases where the retained earth is level with top of retaining wall to $\frac{h}{3}$.

Let t equal thickness of base of wall. Then for safe equilibrium using diagram, Figure 382.

Moment of retaining mass = Moment of sliding wedge-shaped earth mass.

$$W \times vy = P \times \frac{h}{3}$$

$$\text{that is } W \times \frac{t}{6} = P \times \frac{h}{3}$$

in the diagram let qt = W and qr = P, then

$$qt \times \frac{t}{6} = qr \times \frac{h}{3}$$

The value of the effective retaining mass of wall is as follows:—(1) In rectangular vertical retaining walls, it is the weight of the mass of the wall; (2) in retaining walls with sloping backs, as in Figure 386, the sum of the weight of the mass of wall and earth on the wall side of the vertical plane *A B;* (3) in leaning retaining walls, as shown in Figure 387, the mass of wall, minus weight of the earth, which would fill *A B K*, because if this space were occupied by earth, its weight would be supported by the earth beneath it exerting a pressure vertically upwards sufficient to sustain the weight of that triangular prism of earth.

Plane of Rupture.—It has been established by Coulomb, Poncelet and others, that earth in overturning a wall moves forward in a wedge-shaped mass, by sliding down some plane of rupture (as shown in *B C*, Figure 382) which bisects the complement of the angle of repose *B D* starting from the base of the back of the wall. The earth *D B A*, in Figure 386, may be considered as acting with the mass of the wall, and by gravity to equilibrate any earth tending to slide.

If the earth were not retained, the section *A B D* (Figure 382) would particle by particle slip away; but the resistance offered by the friction of the earth and the back of the retaining wall retard this tendency, and it is found by experiment that the part that would have the tendency to first break away and overturn the wall would be the section *A B C*.

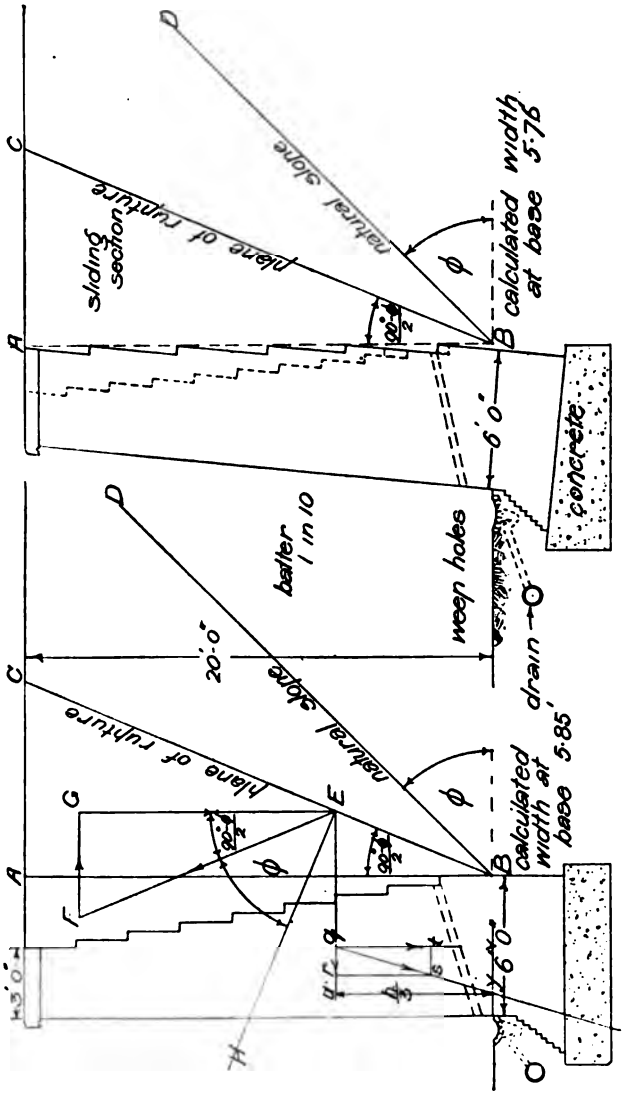


Fig. 383.

Fig. 382.

Maximum Horizontal Thrust.—The sliding wedge-shaped mass of earth indicated by $A\ B\ C$ may be considered to be kept in equilibrium by the friction of the earth, the direction of which force is at an angle to the normal to the plane of rupture equal to the angle of natural slope; this is shown as $E\ F$ in Figure 382, and the reaction of the revetment wall, which may be considered horizontal and acting at E, a height equal to $\frac{h}{3}$ from the base. The value of this component may be obtained graphically very easily. In Figure 382 $G\ E$ is made equal to the weight of the sliding mass, then $F\ G$ is equal to the weight of the wedge-shaped mass multiplied by the tan $\left(\frac{90^\circ - \phi}{2}\right)$. This method is applicable to all revetment walls, whether retaining earth with horizontal or sloping (surcharged) tops. The leverage of the sliding earth masses of surcharged walls will always be greater than those with level tops.

Example 1.—Let it be required to support a bank of earth, 20 feet in height, weighing 120 lbs. per cubic foot, the angle of repose 45 degrees, by a brick wall with a vertical face and a sloping stepped back weighing 120 lbs. per cubic foot, the centre of pressure to fall one-sixth of the thickness from outer edge of wall.

Let ϕ = angle of repose of the earth
t = thickness of base or bed joint of wall
h = height of wall, usually in feet
w_1 = weight per cubic foot of retained earth
W = total weight of retained earth
w_2 = weight per cubic foot of wall material
y = the leverage of the earth mass in terms of the height of the retaining wall
z = the leverage of the wall in terms of t
x = distance of centre of pressure to outer edge of wall
p = pressure per unit of area
then moment of mass of earth = moment of mass of wall

$$W \tan \frac{90 - \phi}{2} l y = (h \times l \times t \times w_2) x$$

$$\text{but } W = \frac{h_2 \tan \frac{90 - \phi}{2}}{2} w_1$$

$$\therefore \frac{h^2 \tan^2 \frac{90 - \phi}{2} l w_1 y}{2} = (h \times l \times w_2) x t$$

$$\text{but } y = \tfrac{1}{3} h \text{ and } x = \tfrac{1}{2} t$$

$$\frac{h^2 \tan^2 \frac{90 - \phi}{2} w_1}{6} = \tfrac{1}{2} w_2 t^2$$

then for level topped walls

$$t = \sqrt{\frac{h^2 \tan^2 \frac{90 - \phi}{2} w_1}{2 w_2}}$$

$$\text{in this case } w_1 = w_2$$

$$\text{then } t = \sqrt{\frac{20^2 \times \tan^2 22\tfrac{1}{2}^\circ}{2}}$$

$$\therefore t = 5{\cdot}8578 \text{ feet}$$

the nearest brick dimension is 6 feet, as shown in Figure 382.

To determine maximum pressure on bed joint:

$$p \times \text{area pressed} = \text{normal pressure on bed joint}$$
$$p \times \text{area pressed} = \text{weight of wall}$$
$$p \times 3 x l = h l t w_2$$
$$p \times 3 \times \frac{t}{6} = 20 \times t \times 120$$
$$p = 4{,}800 \text{ lbs. per square foot}$$
$$p = 33\tfrac{1}{3} \text{ lbs. per square inch}$$
$$\text{but maximum pressure} = 2p = 66\tfrac{2}{3} \text{ lbs. per square inch.}$$

Example II.—Let it be required to support a bank of earth, 20 feet in height, weighing 120 lbs. per cubic foot, the angle of repose 45 degrees, by a brick wall with a batter on face of 1 in 10, and back approximately vertical and weighing 120 lbs. per cubic foot, the centre of pressure to intersect the base so that the maximum pressure does not

exceed $\frac{400}{6}$ lbs. per square inch. Let the wall be supposed to act with a leverage of $\frac{5}{12}\,t$.

The moment of mass of earth = moment of mass of wall

$$W \tan \frac{90 - \phi}{2}\, l\, y = \left(h \frac{t + t\,\frac{h}{10}}{2}\, l\, w_2 \right) x$$

$$\frac{h^2 \tan^2 \frac{90 - \phi}{2}\, l\, w_1\, y}{2} = \left(h \times t - \frac{h}{20} \times l \times w_2 \right) x$$

but $y = \frac{1}{3}\,h$ and $x = \frac{5}{12}\,t$

$$\frac{h^3 \tan^2 \frac{90 - \phi}{2}\, w_1}{6} = 20 \times t - 1 \times 120 \times \frac{5}{12}\,t$$

$$27451 = 1000\,t^2 - 1000\,t$$

$$t^2 - t = 27{\cdot}451$$

$$t^2 - t + \tfrac{1}{2}^2 = 27{\cdot}7$$

$$t - \tfrac{1}{2} = 5{\cdot}26$$

$$t = 5{\cdot}76$$

The nearest brick dimension is 6 feet, as shown in Figure 383. As the earth in this case is of the same weight as the brickwork, the back of the wall might be economically sloped, as shown in Figure 383 by dotted lines.

To determine maximum pressure on bed joint.

p × area pressed = normal pressure on bed joint

p × area pressed = weight of wall

$$p \times 3\,x\,l = h \times l \times \text{average } t \times w_2$$

then x can be calculated or measured from the drawing and equals ·81 feet.

$$p \times 3 \times {\cdot}81 = 20 \times \frac{5{\cdot}76 + 3{\cdot}76}{2} \times 120$$

p = 4701 lbs. per square foot

p = 32·647 lbs. per square inch

but maximum pressure = $2\,p$ = 65·29 lbs. per square inch

Example III.—Let it be required to sustain a bank of earth 20 feet in height, angle of surface slope 30 degrees, angle of repose 45 degrees, weighing 120 lbs. per cubic foot, by a

retaining wall with a vertical face and a sloping stepped back in brickwork weighing 120 lbs. per cubic foot, the centre of pressure to fall one-sixth of the thickness from the outer edge of bed joint. Let the earth encroach beyond the theoretical back AB a distance of $\frac{h}{6}$. Then from Figure 384—

$$AB = h + \frac{h}{6} \tan \alpha = 20 + \frac{20}{6} \tan 30^\circ = 21{\cdot}92 \text{ say } 22 \text{ feet}$$

Moment of mass of earth = moment of mass of wall + mass of earth on top of wall

$$FG \times \text{leverage} = (h \times l \times t) + \frac{\frac{h}{6} \times 2}{2} \times w_2 \times z$$

$$\text{but } FG = \frac{AB \left\{ \frac{AB \times \text{Sin} \frac{90 - \phi}{2} \times \text{Sin } 90 + \alpha}{\text{Sin } B} \right\} w_1}{2} \times \tan \frac{90 - \phi}{2}$$

$$\text{and leverage} = \frac{AD}{3} = \frac{CD \text{ Cot} \frac{90 - \phi}{2}}{3}$$

$$\therefore FG \times \text{leverage} =$$

$$\frac{AB \left\{ \frac{AB \times \frac{\text{Sin } 90 - \phi}{2} \times \text{Sin } 90 + \alpha}{\text{Sin } B} \right\}}{2} w_1 \tan \frac{90 - \phi}{2} \times$$

$$\frac{\left\{ \frac{AB \times \text{Sin} \frac{90 - \phi}{2} \times \text{Sin } 90 + \alpha}{\text{Sin } B} \right\} \text{Cot} \frac{90 - \phi}{2}}{3}$$

$$\therefore \frac{AB \left\{ \frac{AB \times \text{Sin} \frac{90 - \phi}{2} \times \text{Sin } 90 + \alpha}{\text{Sin } B} \right\}^2 w_1}{6} = (20\,t + 3\tfrac{1}{3})\, 120 \times \tfrac{1}{2}\, t$$

$$\frac{22 \left\{ \frac{22 \text{ Sin } 22\frac{1}{2}^\circ \times \text{Sin } 120^\circ}{\text{Sin } 37\frac{1}{2}^\circ} \right\}^2 120}{6} = 800\, t^2 + 133\tfrac{1}{3}$$

$$63117 = 800\, t^2 + 133\tfrac{1}{3}\, t$$

$$t = 8{\cdot}8 \text{ feet nearly}$$

The nearest brick dimension is 9 feet, as shown in Figure 384.

To determine maximum pressure on bed joint:

$$p \times \text{area pressed} = \text{normal pressure on bed joint}$$
$$p \times \text{area pressed} = \text{weight of (wall + earth over wall)}$$
$$p \times 3 \times x \times l = h \times l \times t \times w_2 + 3\tfrac{1}{3}\, w_1\, l$$
$$p \times 3 \times \frac{t}{6} = 20 \times t \times 120 + 3\tfrac{1}{3} \times 120$$
$$p \times 3 \times \frac{8{\cdot}8}{6} = 20 \times 8{\cdot}8 \times 120 + 3\tfrac{1}{3} \times 120$$
$$p = \frac{4800 \times 8{\cdot}8 + 800}{8{\cdot}8}$$
$$p = 4890{\cdot}9 \text{ lbs. per square foot}$$
$$p = 33{\cdot}9 \text{ lbs. per square inch}$$
$$\text{but maximum pressure} = 2\,p = 67{\cdot}8 \text{ lbs. per square inch}$$

Example IV.—Let it be required to sustain a bank of earth 20 feet in height, angle of surface slope 30 degrees, angle of repose 45 degrees, weighing 120 lbs. per cubic foot by a retaining wall with a batter on face of 1 in 10, back approximately vertical and weighing 120 lbs. per cubic foot, the centre of pressure to intersect the base so that the maximum pressure does not exceed $\frac{400}{5}$ lbs. per square inch. Let the wall be supposed to act with a leverage of $\frac{5}{12}\,t$.

$$\text{Moment of mass of earth} = \text{moment of mass of wall}$$

The formula and the value in this case is the same as in Example III.

$$= \left\{ (h \times l \times \text{average } t \times w_2) + \left(\frac{\frac{h}{6} \times 2}{2}\, w \right) \right\} x$$
$$= \left\{ \left(20 \times 1 \times \frac{t + t - \frac{h}{10}}{2} \times 120 \right) + \left(\frac{\frac{20}{6} \times 2}{2}\, 120 \right) \right\} \tfrac{5}{12}\, t$$
$$= [2400\, t - 2000]\, \tfrac{5}{12}\, t$$
$$63117 = 1000\, t^2 - 833\tfrac{1}{3}\, t$$
$$t^2 - \tfrac{5}{6}\, t = 63{\cdot}117$$
$$t^2 - \tfrac{5}{6}\, t + (\tfrac{5}{12})^2 = 63{\cdot}117 + {\cdot}17$$
$$t - \tfrac{5}{12} = \sqrt{63{\cdot}28}$$
$$t = 8{\cdot}316 \text{ feet}$$

The nearest brick dimension is 8 ft. $7\frac{1}{2}$ in., as shown in Figure 385.

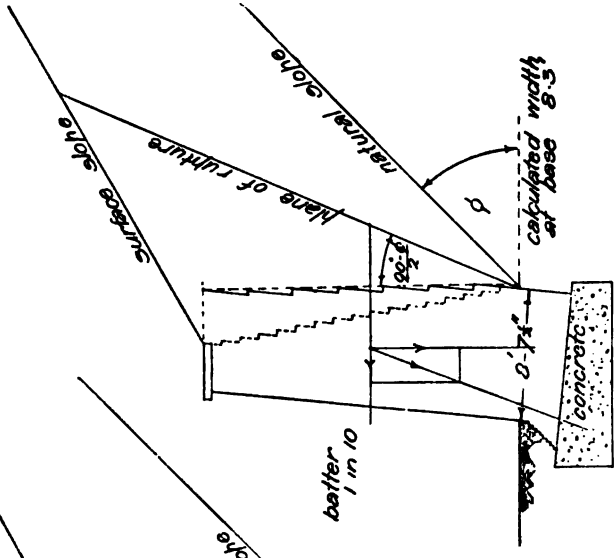


Fig. 385.

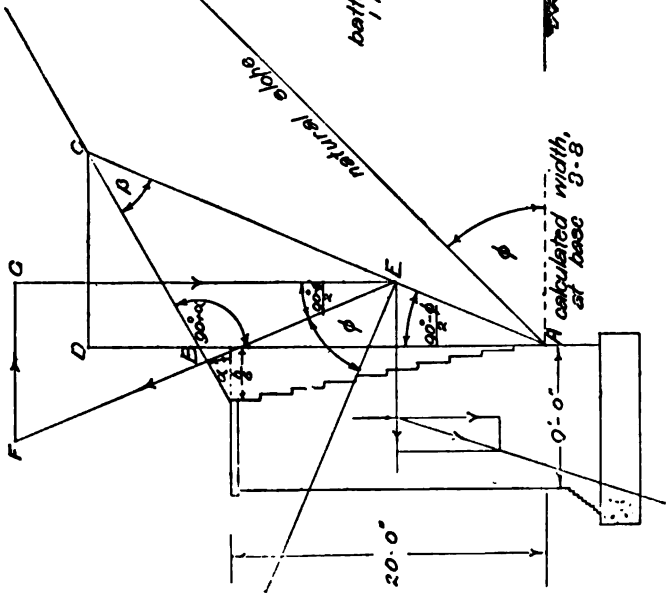


Fig. 384.

To determine the maximum pressure:

$$p \times \text{area pressed} = \text{normal pressure on bed joint}$$
$$p \times \text{area pressed} = \text{weight of (wall + earth over wall)}$$
$$p\, 3\, x\, l = (h \times l \times \text{average } t \times w_2) + 3\tfrac{1}{3}\, w_1\, l$$
$$p\, 3\, x = h \times \text{average } t \times w_2 + 3\tfrac{1}{3}\, w_1$$
$$p \times 3 \times 1{\cdot}089 = 20 \times \frac{8{\cdot}316 + 6{\cdot}316}{2} \times 120 + 3\tfrac{1}{3} \times 120$$
$$p = 5496{\cdot}8 \text{ lbs. per square foot}$$
$$p = 38{\cdot}17 \text{ lbs. per square inch}$$
$$\text{but maximum pressure} = 2\,p = 76{\cdot}34 \text{ lbs. per square inch}$$

Generally.—Cuttings through clay swell if exposed to the air, and exert a force on the back of the wall which is

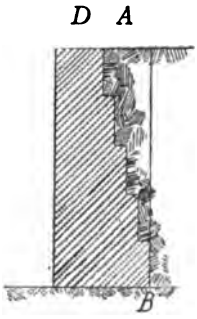


Fig. 386.

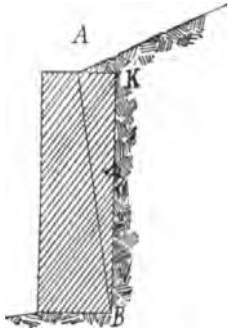


Fig. 387.

difficult to determine. The thickness of the latter must be ascertained by experience.

In calculating for retaining walls, the angle of repose of the earth to be supported must be either known or determined by experiment (the earth being in that state in which by proper drainage it will remain), likewise the weights of the different materials. The former is given on page 171, the latter in one of the chapters on materials.

Should the retained earth be such that when saturated with water it is practically mud, the retaining wall must be

calculated as a dam to resist fluid pressure. The materials usually employed are concrete, brick, and masonry, thoroughly good bond being important in both of the latter.

The backs should be left rough or built in steps, and a layer of loose stone at least 12 inches in thickness, gravel or other porous material to afford a passage of water to the weep holes, should, in retentive soils, be packed up behind the walls, and weep holes not less than 7 square inches in sectional area placed along the bottom, from 5 to 10 feet apart; and in the case of retentive soils, one weep hole to every 4 square yards of face. The weep holes must be connected to a surface drain to protect the foundations and footings, as shown in Figures 382 and 383. In the section of wall usually adopted in practice, the thickness for about one-third the height from the base, is made equal to $\frac{h}{3}$ to $\frac{h}{4}$ and is reduced towards the top in regular offsets at the back.

The face is generally made to batter from 1 in 6 to 1 in 10. Too great a batter in a retaining wall is not desirable, as the wet gets into the joints, and tends to destroy the wall, unless they are pointed with cement. A retaining wall with a batter of 1 in 10 can be bonded easily into an adjacent wall with a vertical face without inconveniently thickening the joints.

A batter is desirable as it economically adds to the stability of the wall, and in the event of any slight outward displacement the wall is not rendered apparently unsafe, as would be the case with a vertical wall.

CHAPTER VII.

ARCHES.

Arches.—An arch is an arrangement of wedge-shaped blocks built about the form of some curve, mutually supporting each other, and being supported at both ends by abutments or piers. They are designed to support the weight of a wall over an opening made in the latter. The important points to be observed in the construction of an arch are as follows:—

1st. Sufficient weight and strength in the abutments to safely resist the overturning moment of the arch thrust.

2ndly. Depth enough in the arch to prevent the weight from above crippling it.

3rdly. Sufficient area in the pier and arch to prevent failure by crushing.

4thly. All bed joints should be perpendicular to the line of least resistance. In practice they are made normal to the curve of the arch, in which position they nearly approximate to normals of the line of least resistance.

Technical Terms.—The following are technical terms used in connection with brick and stone arches:—

Voussoirs.—The courses of bricks or stones which compose the arch.

Springers.—The extreme or lowest voussoirs of arches.

Skewbacks.—The bricks or stones forming the sloping abutments on which the extreme or lowest voussoirs rest, of flat or segmental arches.

Key.—The uppermost or central brick or stone of the arch.

Intrados or *Soffit.*—The under or concave side of the arch.

Extrados or *Back.*—The upper or convex side.

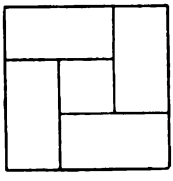


Fig. 388.

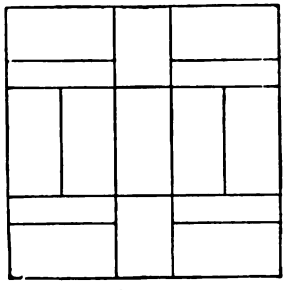


Fig. 389.

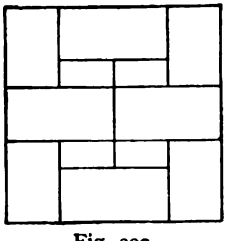


Fig. 390.

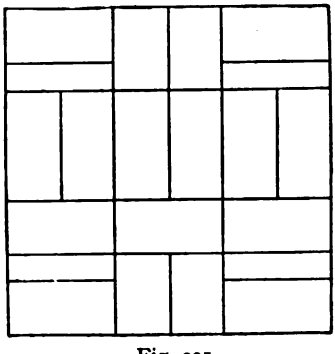


Fig. 391.

Abutments.—Abutments, the outside supports of an arcade, as shown in Figure 397, are piers designed to receive the inclined thrust from one or more arches; they are therefore made of greater weight than ordinary piers by increasing the height or by increasing the width in the direction of the thrust.

Piers.—The intermediate supports of an arcade. They are

rectangular pillars constructed to support heavy weights transmitted to them by beams and girders, or to receive the thrusts of two or more arches, the resultant of the thrusts of which falls in a vertical line.

Figures 393 to 396 show plans of square piers built in English bond, one to three bricks square. It is only

Fig. 393.

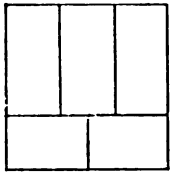


Fig. 392.

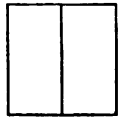
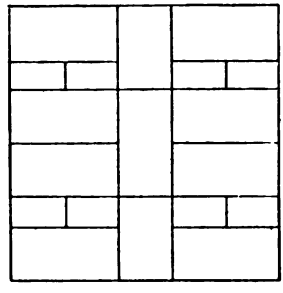


Fig. 395.



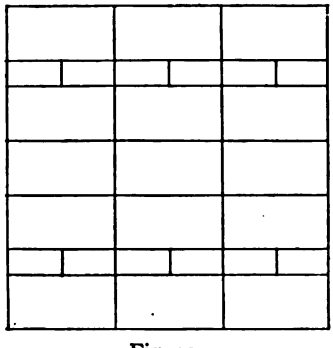


Fig. 394.

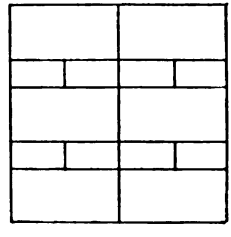


Fig. 396.

necessary to draw the plan of *one* course, as the adjoining courses have the same arrangement of bricks, but placed in such a manner that those in the front elevation of one course are in the side elevation of the next, above or below.

Figures 388 to 391 show plans of square piers built in double Flemish bond one and a half to three bricks square.

Capital.—The name given to the moulded or carved cornice of a column, as shown in Figure 397.

Abacus.—The moulded slab crowning the capital of a column, by which the arch or lintel is supported, as shown in Figure 397.

Impost.—The upper part of a pier or abutment on which an arch rests or from which it springs, generally finished with a moulded cap, as shown in Figure 397.

Arcade.—A series of arches carrying a wall above, and supported by columns or piers, as shown in Figure 397.

Respond.—The semi-column or corbel forming the support of the end arch of an arcade, usually projecting from a flank wall, as shown in Figure 397.

Springing Points.—The points from which the curves of the arch commence, as seen in elevation.

Span.—The horizontal distance between the springing points.

Crown.—The highest point of extrados of arch.

Rise.—The vertical distance between the highest point of the soffit and the level of the imposts or springing points.

Haunch.—The name given to the lower half of the arch, from the springer or skewback, midway to the crown.

Spandril.—The irregular triangular space between two arches, or the space enclosed by vertical lines drawn from the springing of the extrados and the horizontal line tangent to the crown.

Ring Courses of Arches.—The name given to those courses of stone or brickwork that partake of the circular form, as seen on the face of the wall. Figures 398 to 400 give examples in brickwork of $4\frac{1}{2}$-inch rings, whilst Figures 401 to 403 give examples of 9-inch, 14-inch, and 18-inch rings respectively.

Lacing Courses.—The continuity of the ring courses of brick arches is sometimes broken by a bonding or lacing course, as shown in Figure 399. The object of the lacing

courses is to distribute the pressure more evenly over the sectional area of the arch.

Label Course.—The name given to a course of bricks or

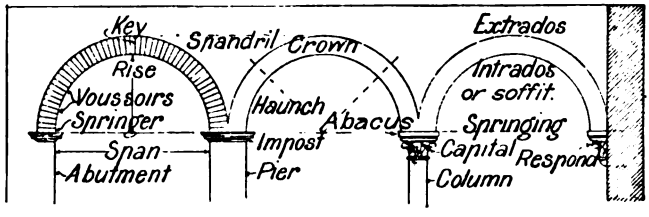


Fig. 397.

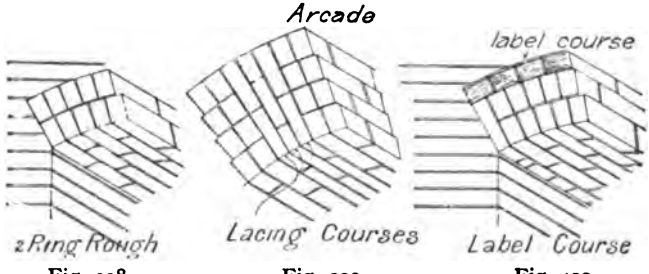


Fig. 398. Fig. 399. Fig. 400.

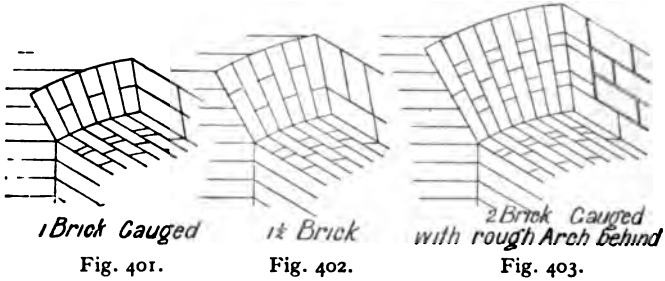


Fig. 401. Fig. 402. Fig. 403.

stones laid flatwise on an arch and deepening it, as shown in Figure 400. These courses usually project and are moulded and weathered on their upper surface to throw all

rain water clear of the arch, and they are frequently made of a different colour to the arch to enhance the effect.

Brick Arch Classification.—Arches may be either gauged, rough axed, or plain brick arches.

Gauged Arches.—These are used for the external faces of walls. They consist of bricks that have been cut and rubbed to a templet. Gauged work is mostly executed in soft bricks, either malms or red rubbers, but sometimes are carried out in harder and in glazed bricks. The side and bed joints are cut and rubbed to the required shape on a stone. Sharp arrises are worked to form a fine joint, which in soft bricks should not be more than $\frac{1}{32}$ of an inch thick. The voussoirs are usually jointed in lime putty to about $\frac{1}{2}$ an inch from the face, the back portion being scored out and grouted in Portland cement. With hard bricks the joints are usually from $\frac{1}{4}$ to $\frac{3}{8}$ of an inch thick.

The depth of flat arches varies to some multiple of the thickness of a brick, being rarely less than 9 inches.

In flat-gauged arches, as shown in Figures 404 to 407, there is a camber of $\frac{1}{8}$ of an inch for every foot of span, to compensate for any settlement, and to prevent the appearance of sagging common to all horizontal lines. To obtain the centre from which the bed-joints are struck, the following rule is adopted:—Set out the top and bottom boundary of the arch, assuming it to be 1 foot in depth, and then mark on each extremity of the extrados $1\frac{1}{2}$ inches for every foot in the clear span of the arch beyond the extremities of the intrados; by joining these points by a line the inclination of the skewbacks is obtained, and if the line be produced, the intersection gives the centre of the arch. The true depth of the arch may then be set out. It is necessary that there should be an odd number of bricks in an arch in order to obtain a key, and it is preferable that the odd number is such that the heading joints in springers and keys are at the same level, and these must be so struck that they can

Fig. 404.

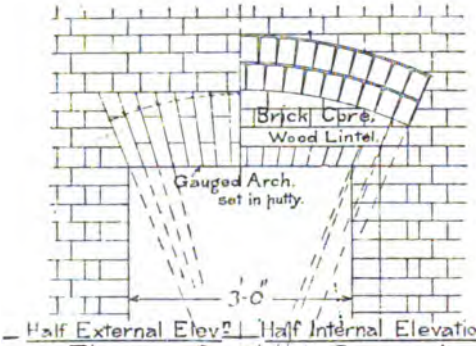
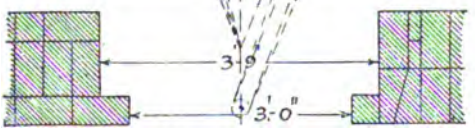


Fig. 405.

Half External Elev.ⁿ Half Internal Elevation. Section.

Flat or Camber Gauged Arch.



Plans.

Fig. 406.

Fig. 407.

Sketch of Voussoir showing Grout Channel.

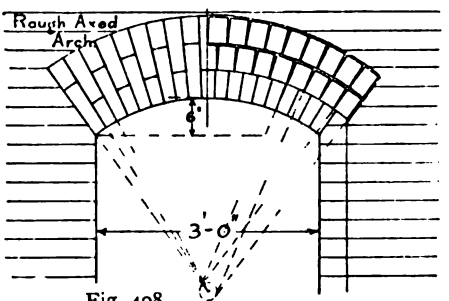


Fig. 408.

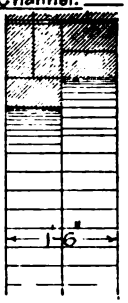


Fig. 409.

Segmental Arch.

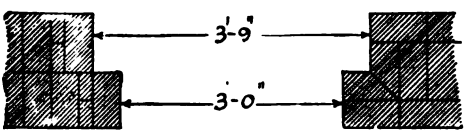


Fig. 410.

all be cut from one templet. To do this a curve must be struck from the centre found by the intersection of the skewbacks produced, tangent to the extrados of the arch, and the voussoirs must be divided out on this curve, as shown in Figure 404.

Figures 408 to 410 show a segmental gauged arch with a discharging arch of concentric outline at the rear.

Outline of Arches.—The name by which an arch is known

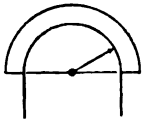


Fig. 411.

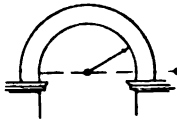


Fig. 412.

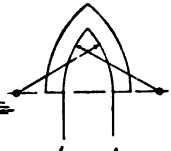


Fig. 413.

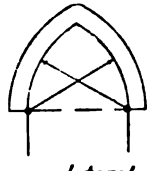


Fig. 414.

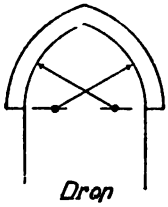


Fig. 415.

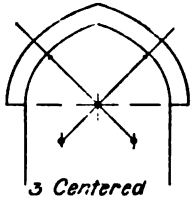


Fig. 416.

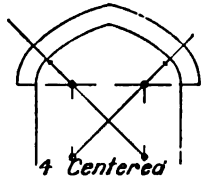


Fig. 417.

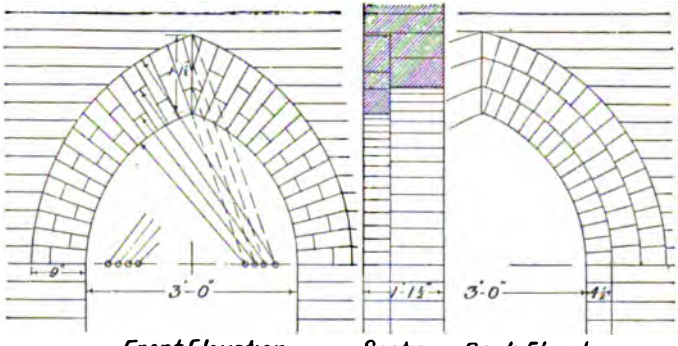
is generally that of the curve of which the arch is a segment.

Figures 411 to 423 show the methods of setting out the semi-circular, stilted, lancet, equilateral, drop, three-centred, four-centred, Venetian pointed, and Florentine forms of arches.

The setting out of the first seven is obvious. The depth of the arch at the springing in the Venetian pointed must be given, the curve of the extrados and heading joints subtend at their centres similar angles to that subtended by the arc

of their intrados, as shown in Figures 418 to 420. In the Florentine, as shown in Figures 421 to 423, the intrados is a semi-circle, therefore the depth at the springing and

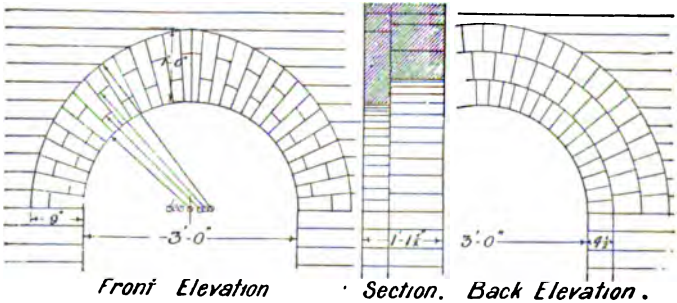
Fig. 418. Fig. 419. Fig. 420.



Front Elevation. Section. Back Elevation

Venetian Pointed.

Fig. 421. Fig. 422. Fig. 423.



Front Elevation Section. Back Elevation.

Florentine.

crown must be given. The centre will be upon the springing line at the intersection of the bisecting line of the line joining the crown and the springing of the extrados or heading joints.

Elliptical Arches.—The curve of the ellipse is usually struck for most practical purposes by the trammel. This is inconvenient for brick arches owing to the amount of labour in determining the bed joints, all of which should be normals to the intradosial ellipse; and further, if this were done each voussoir would be of a different shape, and require a separate templet. This may be avoided by striking a curve from three centres, as shown in Figure 424, which

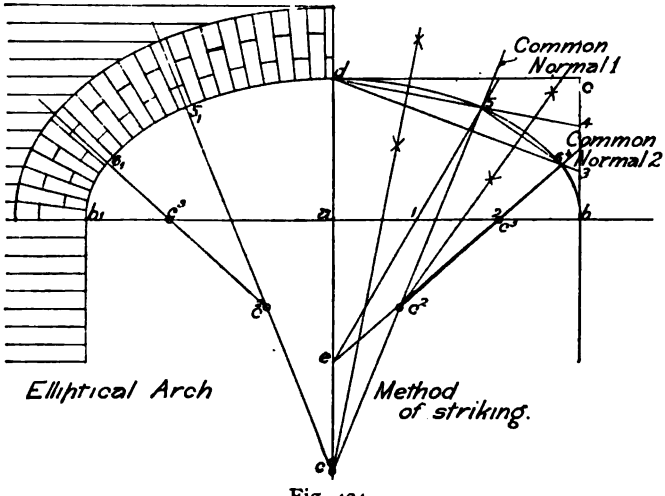


Fig. 424.

can be made a very close approximation to a true ellipse, and requiring only three templets to cut the voussoirs. To strike the semi-arch, let a rectangle be described having for its sides the semi-major and semi-minor axes, divide the lines *a b* and *b c* each into three equal parts at points 1, 2; 3 and 4. From the points 3 and 4, draw lines to the point *d*, and from *e*, which is distant from *a* a length equal to *a d*, draw lines through points 1 and 2, the intersection of the lines drawn through 2 and 3 and 1 and 4 are points

Fig. 425.

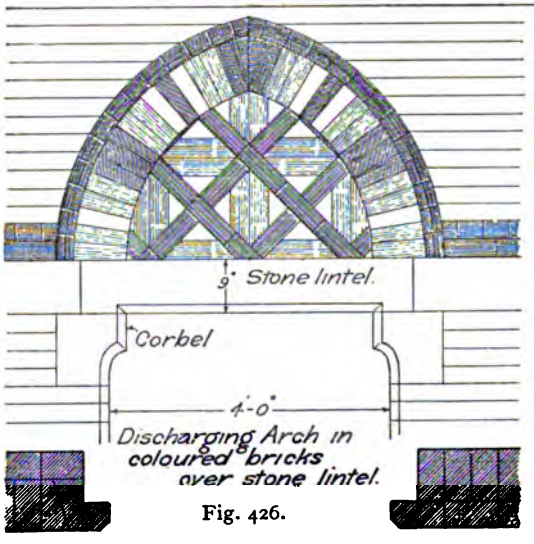


Fig. 426.

Fig. 427.

Fig. 428.

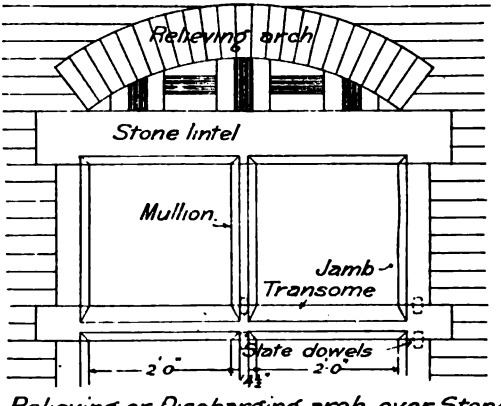
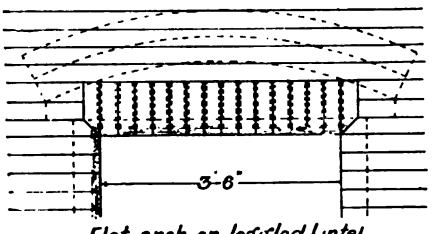


Fig. 429.

Relieving or Discharging arch over Stone lintel.

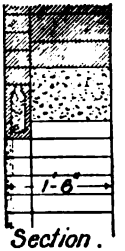
Figs. 425–429. Arches with Coloured Treatment.

in the curve of a true ellipse. To find the first centre *c*, draw a line from *d* to 5 and bisect it, at the intersection of the bisecting line and the minor axis produced will be the first centre. Join c^1 and 5, this will be the common normal between the curves *d*.5 and 5.6, and must therefore contain centre No. 2, which may be found by bisecting a line joining 5 and 6 and producing till it cuts the common normal c^1 5. From c^3 draw a line through point 6, this will be the second common normal and will contain c^3. The intersection of common normal 2 with springing line will give the third centre. All the bed joints of the voussoirs are



Flat arch or Joggled Lintel.

Fig. 430.



Section.

Fig. 431.

struck from the centres of the segments in which they are situated.

Figures 425 to 427 show a gauged relieving arch treated by an ornamental arrangement of coloured bricks in the tympanum.

Figures 428 and 429 show a gauged relieving arch over a stone lintel. It is unnecessary for the relieving arch to spring from the extremities of the lintel, as in this case the lintel is of a material which is as durable as the material of the arch.

Flat Gauged Arch or *Joggled Lintel*, as shown in Figures 430 and 431. This is employed in openings in glazed brickwork and where it would be difficult to cut the bricks to the

necessary wedged form. The bed surfaces of the bricks are rubbed to obtain a thin joint, they are then built upon a turning-piece and the frogs (of which there are two on

Fig. 432.

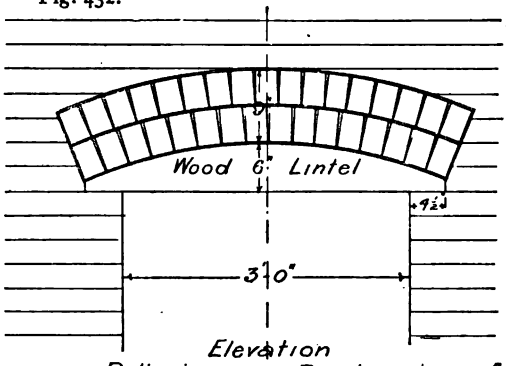
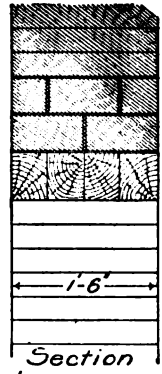


Fig. 433.



Relieving or Discharging Arch

Fig. 434.

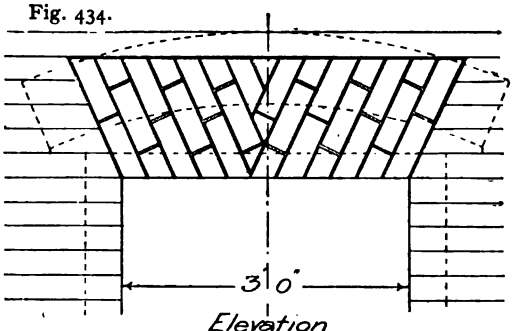
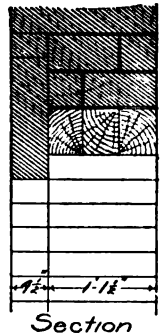


Fig. 435.



French or Dutch Arch

each brick) filled with Portland cement grout, which forms a joggle.

It is unwise to use these in openings greater than 4 feet. Above that span the bricks should be perforated and an iron bolt passed through.

Rough Relieving or *Rough Discharging Arches* are usually formed by laying ordinary bricks on edge (without being cut or rubbed), on rough centres, or turning-pieces, or on a brick core shaped to the required curve, as in Figure 404, or on a curved wood lintel, illustrated in Figures 432 and 433. It will be seen that the joint is much wider on the extrados than on the intrados, as all the joints are **V**-shaped in elevation. If arches of this description were built in 9-inch rings this defect would be serious; consequently they should be constructed in $4\frac{1}{2}$-inch rings, as shown in Figure 432, which to a great measure reduces the imperfection. These are chiefly used for internal arches over doors and windows where they will be covered with plaster. A relieving arch is usually placed behind a gauged brick arch, to relieve the latter of the superincumbent load.

Inverted Arches.—These are rough arches inverted, springing from piers or abutments upon which the bulk of the weight is concentrated, and with which there would be a possibility of unequal settlement with the remainder of the wall, due to the ground under the foundation being subjected to a non-uniformly distributed stress. Their effect is to distribute the pressure uniformly along the whole length of the foundation. The minimum rise should be about one-fifth of the span, as illustrated in Figure 42.

Dutch Arch.—Figures 434 and 435 show a rough brick arch, known as the French or Dutch arch, which is often used for external arches that are to be plastered over to avoid the expense of a flat gauged arch. It is only used in rough work, and is of weak construction.

Trimmer Arches.—These are a form of rough arch adopted for supporting hearths in front of chimney breasts, and having an abutment against the trimmer or trimming joists, as shown in Figure 576.

Rough Axed Arches.—These arches are employed where it is required to have a strong arch of a neat appearance

for the elevations of factories or warehouses, etc. The voussoirs are of the ordinary well-burnt facing brick, and are neatly cut with the bricklayer's axe to the required shape.

Fig. 436.

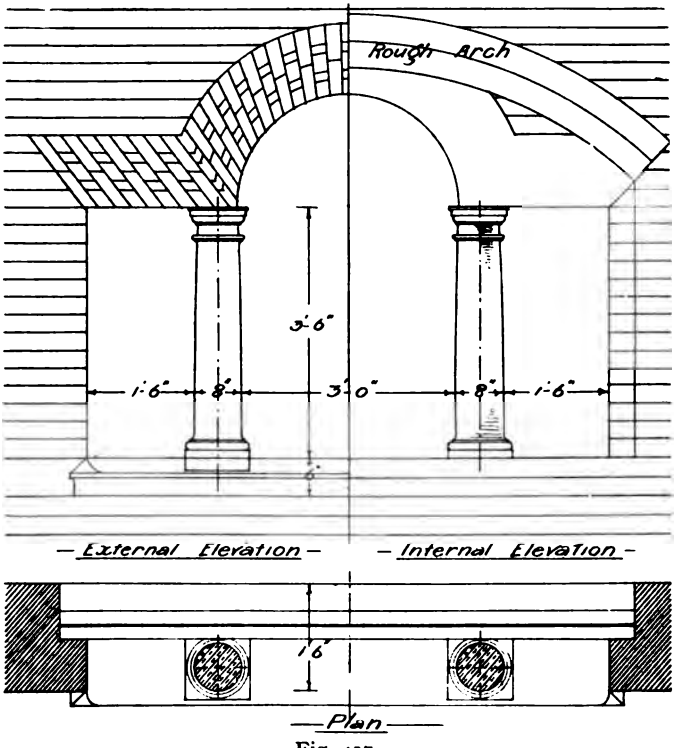


Fig. 437.

The roughly-cut surface forms a good key for the mortar and resists the sliding tendency of the voussoirs. The joints vary from $\frac{3}{16}$ths to $\frac{3}{8}$ths of an inch.

Three-Light Opening.—This, which is sometimes known as a Venetian arch, consists of an opening divided into

three by light stone columns or small brick piers, the central opening usually being semi-circular, as shown in Figure 436, the arch, if of brick, is gauged. The portions surmounting the two side openings have their bed joints at

Fig. 439.

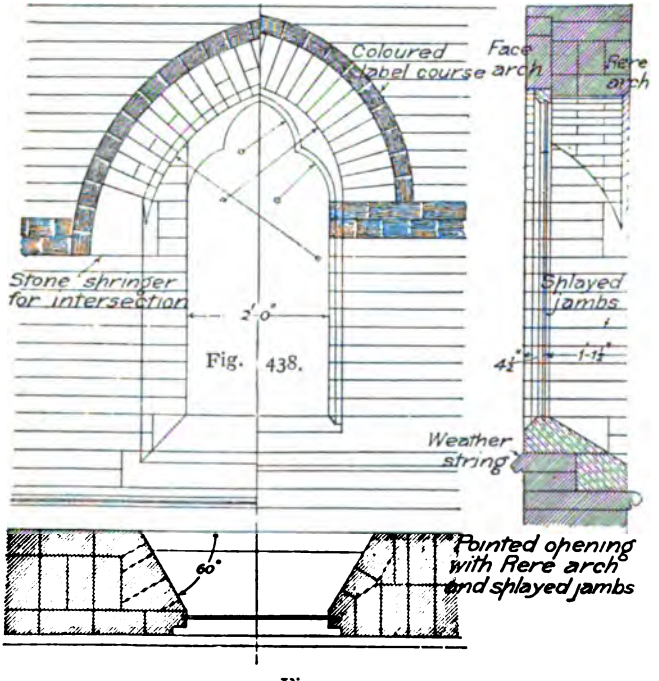


Fig. 440.

a constant angle, ranging between 50 degrees and 60 degrees. The bed joints for the central arch radiate from the point on the centre line at which lines drawn at the constant angle from the springing points intersect.

Pointed Arch with Rere-Arch.—Figures 438 to 440 show an opening formed with splayed internal jambs, pointed

arch, and stone cusps externally, and pointed barrel rere-arch internally, which is the method adopted in arcuated openings where splayed jambs are employed. The intersection of the rere-arch and splayed jambs shown in Figure 439, is obtained by drawing a number of vertical lines on the splayed jambs shown in the internal elevation (Figure 438), and drawing these lines on the jamb in the sectional elevation, and projecting from the internal elevation the points of intersection of these vertical lines with the barrel arch; joining these projected points in the sectional elevation will give the curve in this projection.

Arch Built with Orders.—This is another treatment of the arch when employed in the openings of very thick walls, where the arch consists of a number of rings similar to a rough arch. It is a common practice to diminish the width of each ring from the outer (which is generally in width the full thickness of the wall) to the inner ring, the width of which is very much smaller, thus forming a number of receding planes: each of these rectangular rims is termed an order. This relieves the opening of the clumsy and heavy appearance that is attendant upon a square opening in such a position; it also admits of the distribution of light inside to a much greater extent than is the case with a square opening. The jambs inside such an opening are usually splayed; the inner edge of the splay may be carried round the outer arch in a concentric curve or curves, or the inner arch may be an ordinary barrel arch, with its crown at or near the same height as that of the outer, and with the springing line much lower, thus forming a curved line of intersection on the internal jambs and soffit. The edges of the external receding planes are often richly moulded. The orders may rest at the springing of the arch on the abaci of small collonettes, or they may be continued to the sill, as shown in Figures 441 to 443.

Lintels.—These are horizontal members placed over square openings to form the head and support the work

Fig. 441.

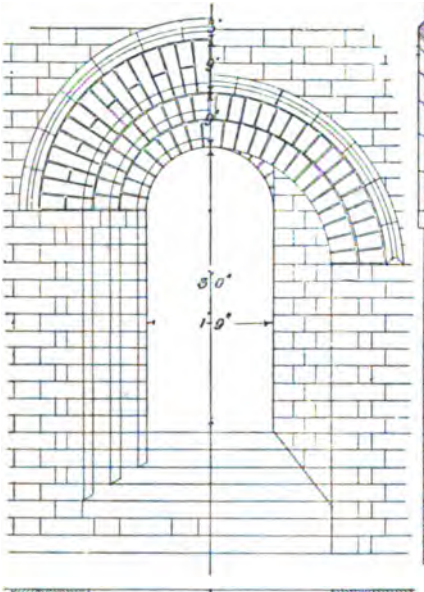
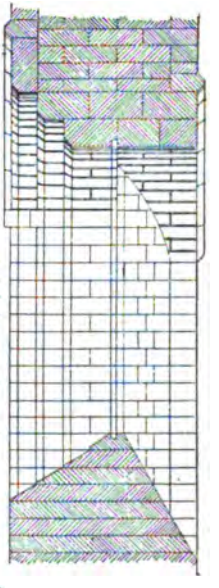


Fig. 442.



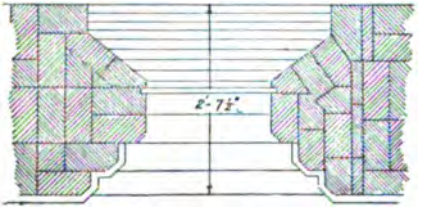


Fig. 443.

above; they may be of wood, iron, coke-breeze concrete; stone, or brick.

Wood Lintels.—These consist of pieces of timber from 4½ in. by 3 in. upwards, according to the span of the opening;

they are generally assisted by a rough brick arch as a precautionary measure in the event of the timber being destroyed. The space between the lintel and the arch is filled with a brick core, see Figure 404. The lintel sometimes has its upper surface curved, thus forming a turning piece for arch, see Figure 432.

Steel Girders.—These are generally used where the openings are very wide, and where there is no space for an arch above, as shown in Figure 229.

Coke-breeze Concrete.—This is formed of 4 parts by volume of coke-breeze to 1 of Portland cement, and is often employed, being to a certain extent fire-resisting and admitting of joinery being fixed to it, as it will hold nails and screws with great tenacity. These lintels are often curved on their upper edge, in which case they are relieved by an arch above, or they are made straight on their upper surface and their depth is increased. Where used for wide openings, tensional strength is obtained by embedding one wrought-iron bar for each half brick in the thickness of wall, supported by lintel $\frac{1}{2}$ inch thick and having a depth of $\frac{1}{2}$ inch for each foot of the span.

Stone Lintels.—Stone is unsuitable to withstand transverse stresses, and should never be used for openings above 3 feet in span unless relieved of the weight above by a discharging arch or save stones, as shown in Figures 425 and 447; otherwise, they would require to be abnormally deep.

Stone Arches.—The openings in stone of small span are generally bridged by stone lintels in one piece, or lintels built on an arched construction if a number of stones are used. If lintels of one piece are employed in walls other than ashlar, a rough arch is generally built above to relieve the lintel of the weight of the superincumbent wall, as shown in Figures 444 to 446. A second method of relieving the lintel commonly adopted in snecked rubble work

Fig. 444. Fig. 446.

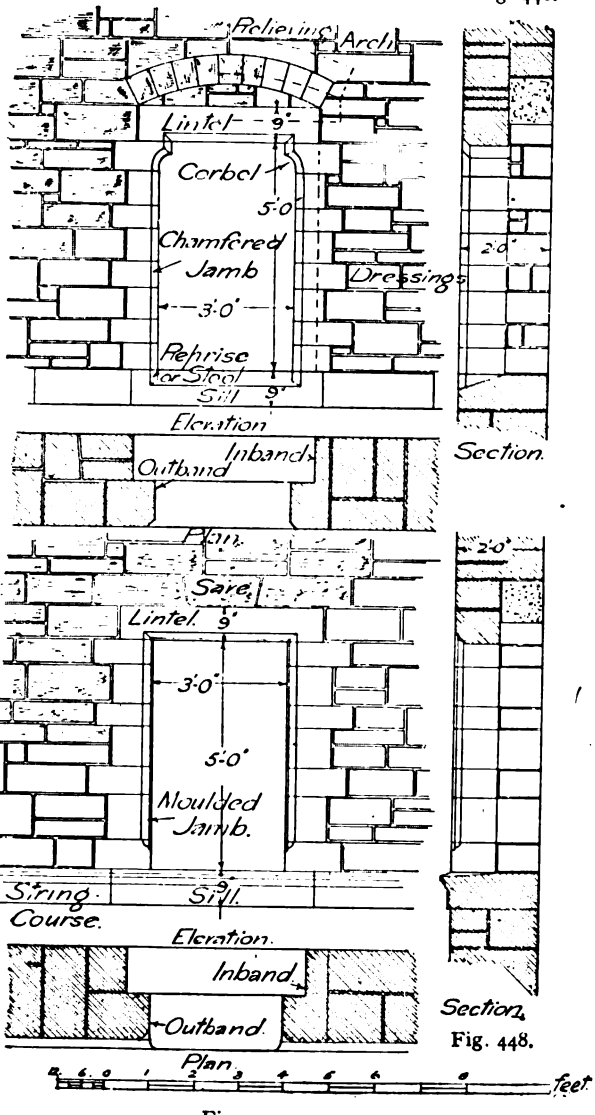


Fig. 445.

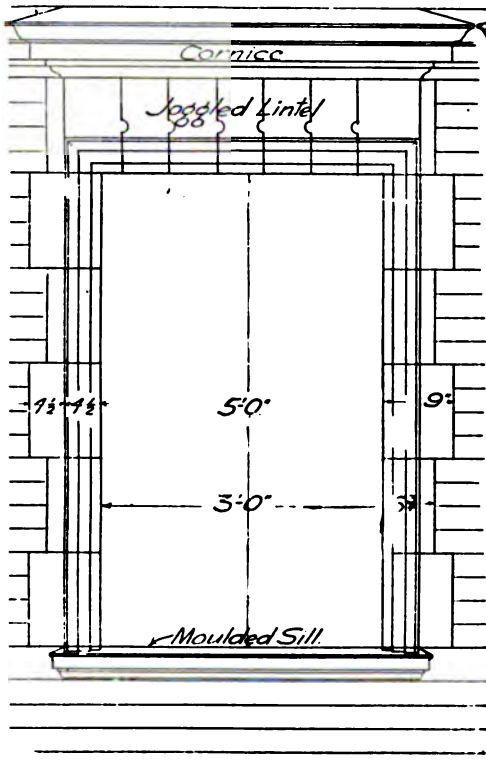
Fig. 447.

Fig. 449.

Fig. 448.

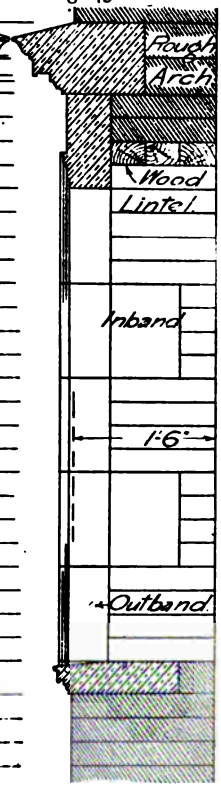
Figs. 444–449.

Fig. 450.



Elevation.

Fig. 451.



Section.

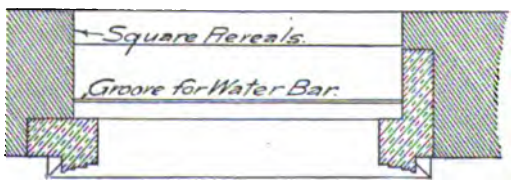
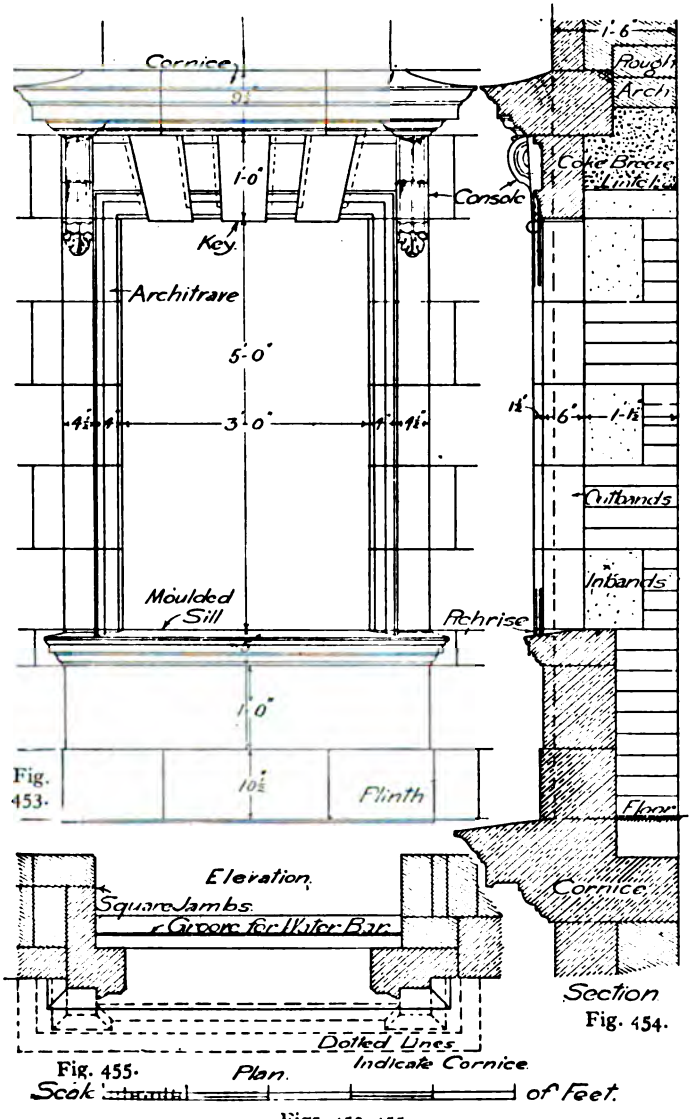


Fig. 452.

Plan

Scale 0 6 1 0 1 2 3 4 of Feet.

Figs. 450-452


Cornice
1'-0"
Key
Architrave
5'-0"
3'-0"
4½"
4"
4"
4½"
Moulded Sill
1'-0"
10½"
Plinth
Fig. 453.
1'-6"
Rough Arch
Coke Breeze Lintel
Console
1½"
6"
1'-1½"
Outbands
Inbands
Rebrise
Floor
Cornice
Section
Fig. 454.
Elevation
Square Jambs
Groove for Water Bar
Dotted Lines Indicate Cornice
Plan
Fig. 455.
Scale of Feet

Figs. 453–455.

is to construct a flat arch of three stones above the lintel, as shown in Figures 447 to 449; the centre stone or key is termed the save. In bedding the save stones no mortar is placed on the lintel, but the stones are supported in their position by means of small wood wedges. After a sufficient mass of the wall has been built to tail down the side saves the wedges are removed. In finishing the wall, the joint between the saves and the lintel is pointed only, thus no weight from the wall above is brought to bear on the lintel.

A large number of stone openings are formed with flat heads, and where stones of sufficient dimension cannot conveniently be obtained in one piece, some form of flat arch is adopted.

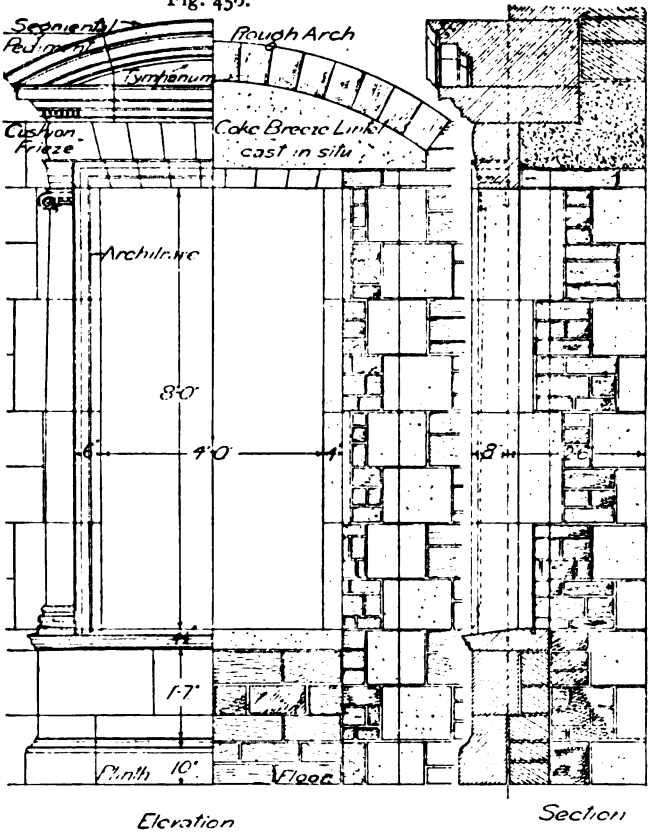
Figures 450 to 452 show a joggled lintel in this example; the joints are vertical, the intermediate stones being kept in their place by a semicircular joggle from front to back of every pair of bed-joints in the centre of each block. This form is also largely used for terra-cotta work.

Figures 453 to 455 show a flat arch, with secret joggles. These latter are worked out of the solid stone, the key having two joggles; the springer is recessed only, and is made sufficiently long to tail well into the wall, the remaining voussoirs being joggled on one bed-joint and recessed on the other; the cornice over window in this example is supported by a console or bracket.

Figures 456 to 458 show the construction as a flat arch, the bed-joints stepped to prevent any voussoir sliding on its bed-joint. This method is largely used for terra-cotta work. This example illustrates an architrave about window, supported at sides by a half column with cushion frieze and segmental pediment above. The internal jambs are splayed, and illustrate the use of scontions. A coke breeze lintel cast *in situ* is shown over the internal opening,

Fig. 456.

Fig. 457.



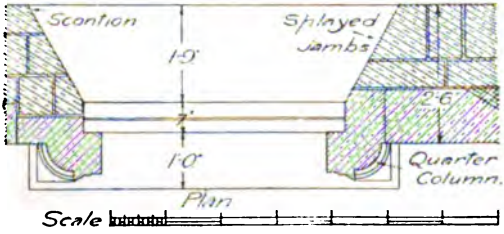


Fig. 458.

Figs. 456–458

Fig. 459.

Fig. 460.

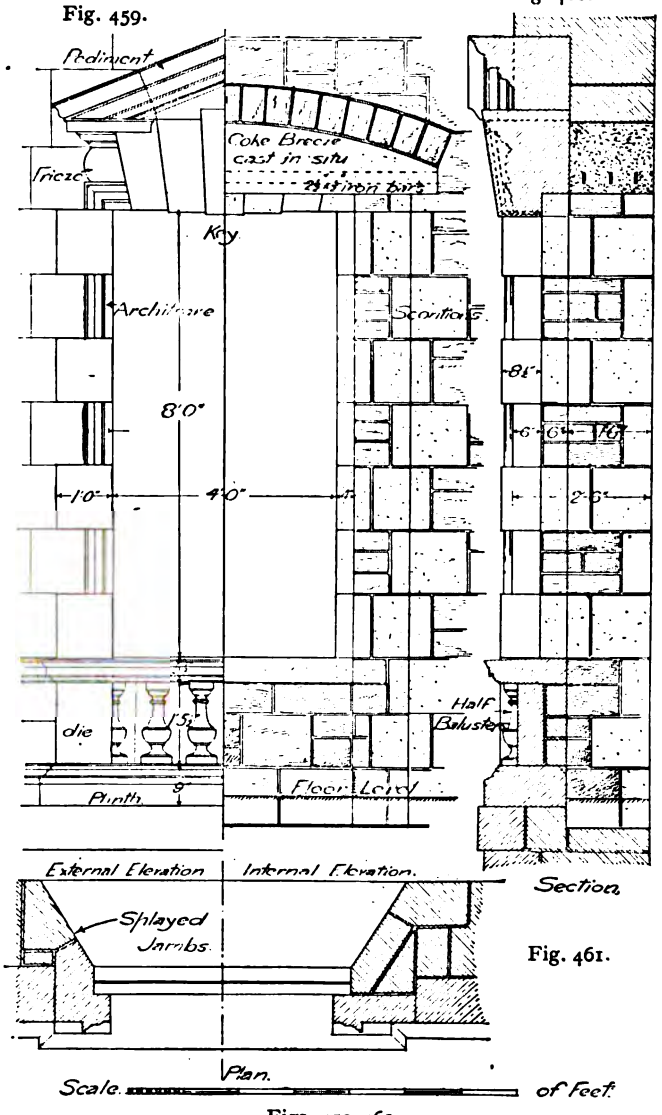
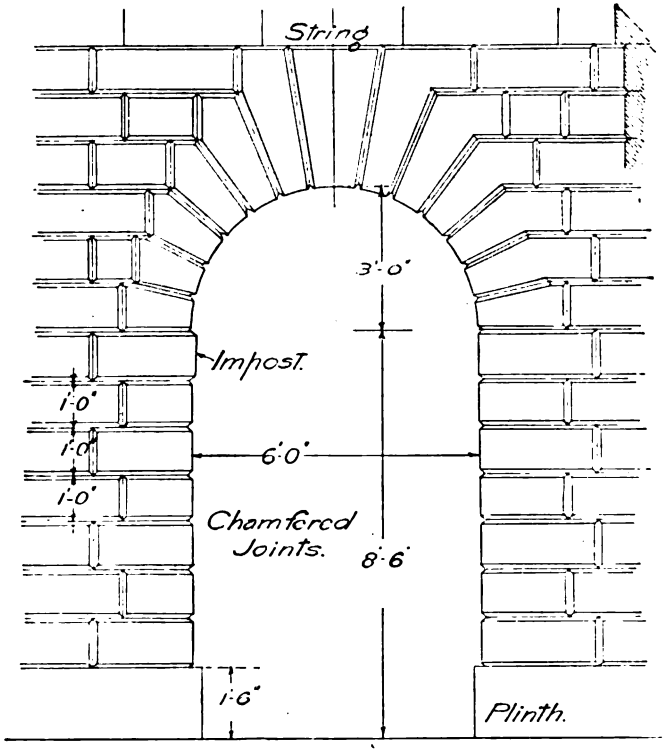


Fig. 461.

Figs. 459–461.

Fig. 462.



Elevation.

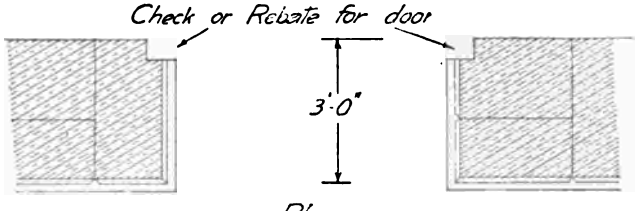


Fig. 463.

Plan.

the upper surface being segmental; upon this a rough stone arch is constructed to relieve the lintel.

Figures 459 to 461 show a flat arch with projecting voussoirs. About the opening is an architrave with a frieze and pediment over. The first voussoir projects sufficiently to interrupt the frieze and bed moulding, the second voussoir projects about an inch beyond the first and extends upwards to the top of the corona, the latter being returned in itself against the first vousssoir to prevent an unsightly intersection. The key projects about an inch further and extends into the tympanum of the pediment. The architrave is interrupted by rectangular blocks, the latter projecting about half an inch.

Fig. 465.

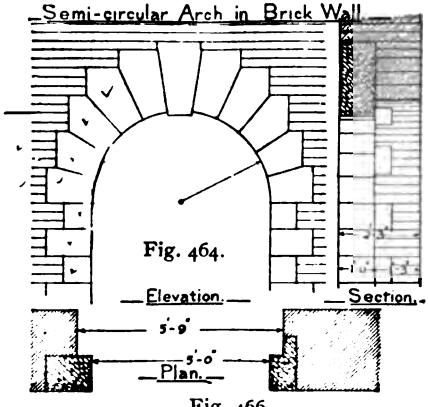


Fig. 466.

The sill forms the cornice of a pedestal as shown, being supported beneath the opening by stone balusters. The internal opening has splayed jambs with a coke breeze concrete lintel strengthened by iron bars, and being segmental on upper surface. This form of lintel is extensively used where the pressure from above is considerable. The lintel is relieved by a rough discharging arch.

Figures 462 and 463 illustrate a semicircular opening in an ashlar wall, the blocks of which have chamfered joints. In these arches it is necessary to extend the bed joints of the voussoirs till they intersect the courses of the work;

Fig. 467.

Fig. 468.

Fig. 469.

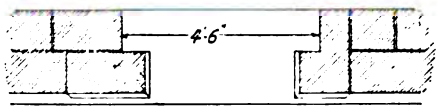


Fig. 471.

Fig. 470.

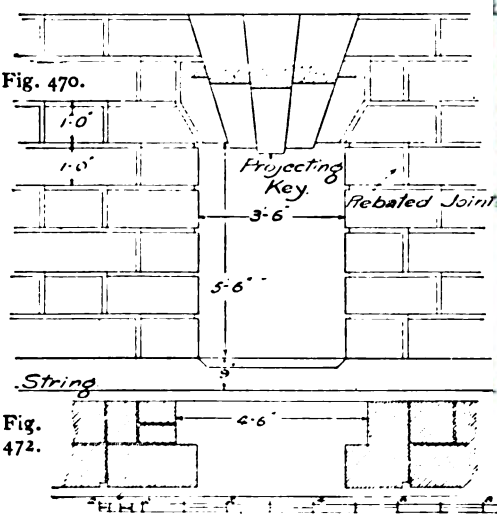


Fig. 472.

Figs. 467–472.

this results in the voussoirs gradually getting longer as they approach the key. Another method of arranging voussoirs is shown on right hand of Figure 462. In this the bed joints of the voussoirs are extended to meet the horizontal courses, and are then returned a convenient distance along the horizontal course; this prevents the vertical joints of the voussoirs coming too close together near the springing.

Figures 464 to 466 show a semicircular stone arch built in a brick wall.

In setting out the voussoirs are divided up equally on the soffit, and the bed joints are struck radially from the centre.

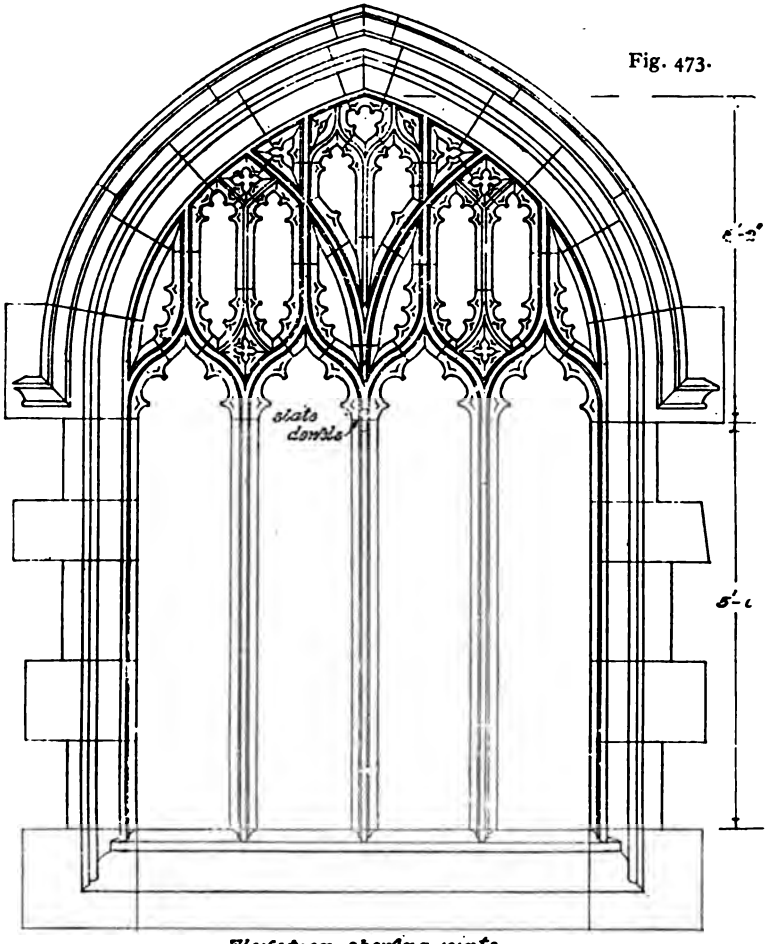
The greatest width of the voussoirs is made to equal some multiple of the thickness of a brick, 3, 4, or 5 courses as required. The first bed joint is produced till it cuts the desired bed joint of the bricks. The boundary of the voussoir from this point deflected horizontally for about 4 inches to 6 inches and vertically upwards for another 4 or 5 courses, the second radial joint is then struck and produced to the same level; these two points are joined by a horizontal line and the second voussoir is then completed. This operation is repeated till the arch is finished. It should be observed that the depth of the arch increases towards the crown, as set out by this method.

In all wrought stonework the voussoirs are accurately set out with templets and cut.

Figures 467 to 469 show a rectangular opening, spanned by an arch, the dressings and voussoirs of which project beyond the wall face about $1\frac{1}{2}$ inches, have chamfered joints and are vermiculated on surface to give importance to the opening; this form of opening is commonly adopted in the basement stories of classical buildings.

Figures 470 to 472 show a similar opening, the voussoirs projecting as they approach the key, and the joints of the

Fig. 473.



Elevation showing joints

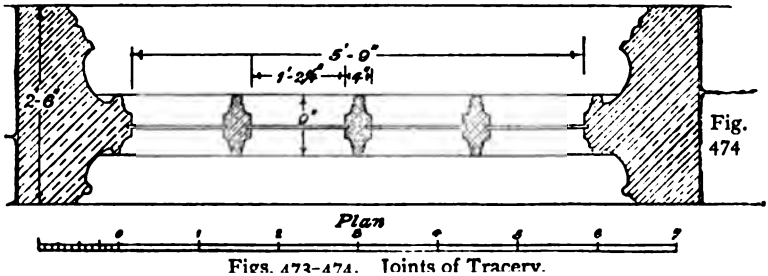


Fig. 474

Plan

Figs. 473–474. Joints of Tracery.

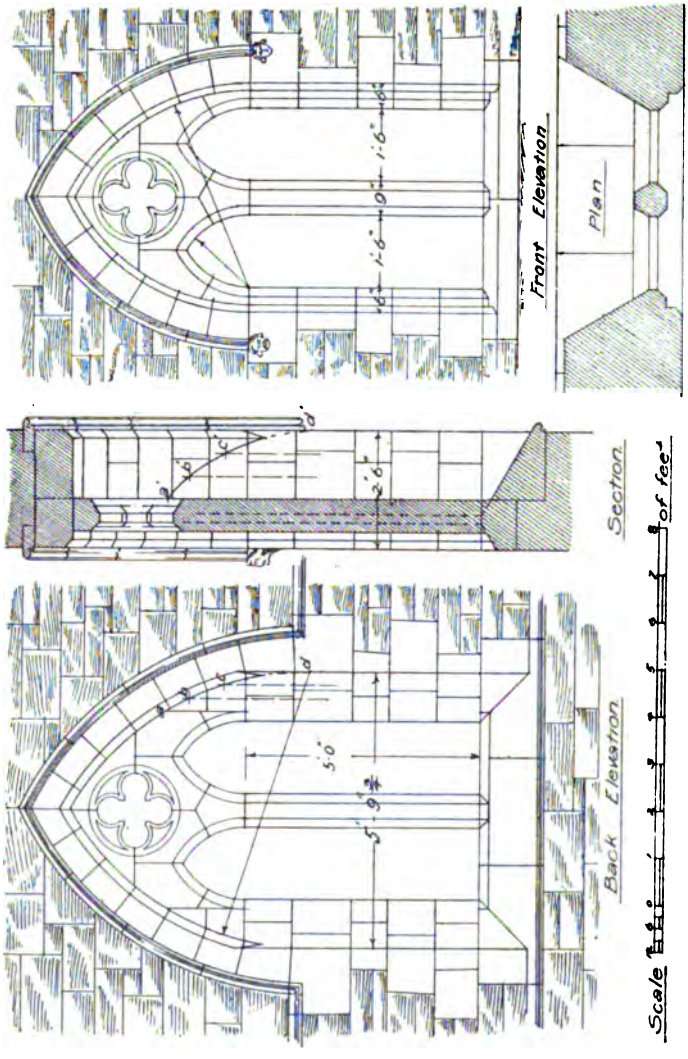


Fig. 475.

Fig. 476.

Fig. 477.

Fig. 478.

masonry being rebated. This is also used for basement stories of classical buildings.

Stone being a granular material, anything approaching an acute angle is liable to weather badly, therefore in any tracery work having several bars intersecting, a stone must be arranged to contain the intersections and a short length

Fig. 479. Fig. 480.

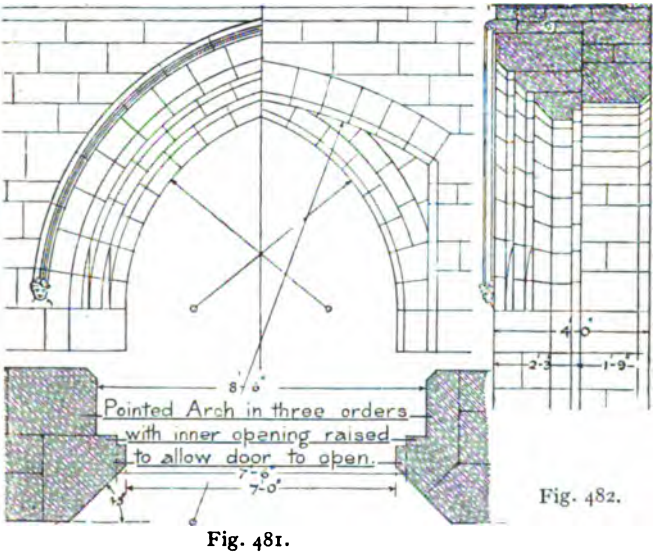


Fig. 481. Fig. 482.

of each bar, as shown in Figure 473, and the joints should be (*a*) at right angles to the directions of the abutting bars if straight, or (*b*) in the direction of a normal to any adjacent curved bar. This not only prevents any acute angles occurring, as would be the case if the joints were made along the line of intersection of the moulding, but also ensures a better finish, as the intersection line can be carved more neatly with the chisel, and is more lasting

than would be the case if a mortar joint occurred along the above line. In no case, either in tracery, string courses, or other mouldings, should a joint occur at any mitre line.

Figures 475 to 478 illustrate the jointing and building up of a pointed arch with plate tracery and a rere-arch. Figures 479 to 482 illustrate a pointed arch in three orders with inner opening raised to allow door to open.

Tracery.—Wherever the moulded members of the tracery admit of it the practice should be followed of designing the tracery and fitting in rebated stone reveals, similar to the method of fixing wood frames in reveals, as it is found to be easier to fix the tracery after the opening is built.

Bridge Construction.—Bridges constructed of brickwork or masonry are built in the following manner: the span of arch or arches and their rise and radius are determined upon; from these the depth of the arch may be obtained by employing Rankine's formula. Next the external spandril walls with the footpath and roadway are designed; the latter is supported by internal spandril walls, these being arched over or covered by slabs of stone to form a platform upon which the road can be built. The spandril walls where high are stiffened by means of cross or tie walls at intervals, as shown in Figures 488 to 490.

Let it be required to construct a bridge of 50 feet span and with a rise of 21 feet, the arch and external spandril walls to be of granite, the internal spandril and tie walls of brick, the spandril walls to be connected by brick arches upon which a bed of concrete is laid to form a foundation for the road consisting of granite sets and the footpath of 2-in York paving.

	Weight o materials per cubic foot in lbs.
Granite	170
York Stone	165
Brickwork in Cement	115
Concrete (1 to 6)	140

Let the moving or live load on bridge be computed as 1 ton 19 cwts. per foot run of bridge, which should be doubled to obtain its equivalent dead load, viz.:

3 tons 18 cwts. per foot run of bridge.

The depth of the arch, using Rankine's formula, equals $\sqrt{\cdot 12 \text{ radius in ft. at crown}} = \sqrt{\cdot 12 \times 25} = 1\cdot 732$, that is, 1 foot 9 inches, nearly.

The dimensions of all parts of the bridge are given in the Figures 484 to 490.

To determine the stability of the arch let the bed joint of the first voussoir, which unsupported from above would overturn, be considered as the commencement of the arch proper, the lower voussoirs between this point and the springing being considered as corbels. Let the remaining portion of the arch on one side of the centre line be divided into six equal sections, then the weights in tons of these sections with the road, load, and balustrade computed will be as in the following table:—

	1	2	3	4	5	6
Road, load, and balustrade ...	46·768	46·768	46·768	46·768	46·768	46·768
Spandril ...	·165	1·765	4·965	10·261	17·874	29·459
Arch	19·484	20·364	21·248	23·457	27·444	28·097
Total ...	66·417	68·897	72·981	80·486	92·086	104·324

Let the vertical lines passing through the centres of gravity of each of these sections be drawn as shown in Figure 483, then determine the pathway of the resultant force, and the line of least resistance under the given distribution of the load, as shown in Figure 483.

Let the arch now be tested for stability by satisfying the conditions of stability for uncemented blocks already given in the chapter on "Brickwork," and illustrated in the case of

the stability of the arch in the chapter on "Graphic Statics," "Mitchell's Advanced Building Construction." If it is found that the proposed distribution of the load causes the line of resistance to fall without the prescribed limits, viz., without the middle third of the arch ring, as shown in Figure 483, the load will have to be readjusted or added to, so that a line of resistance may be obtained that will fall within the middle third.

It will be found by inspection of the diagram, Figure 483, that the line of least resistance falls outside the limits and approaches the intrados of the arch; the arch would therefore tend to open at the extrados at the haunches. Referring to the diagram, Figure 485, the line of resistance has been raised to the least amount so that every part of it falls within the middle third. Now construct a new force polygon, the force *Q-a* being the only force having the same value as in the first force polygon, by means of lines drawn parallel to the modified polar polygon or line of resistance. Parallels to lines of resistance on spaces *Q* and *a*, drawn from *Q* and *a* on force polygon, will intersect in pole *f*, then from this pole draw parallels to sides of polar polygon on spaces *b, c, d, e, P*, these parallels will intersect *Q-a*, produced in points *b, c, d, e, P*, this will give the required force polygon from which may be measured the adjusted loads, and the amount to be added at each section. The following table shows the weight to be added, which may be in the form of concrete:—

	1	2	3	4	5	6
Required load	66·417	69·155	73·756	82·036	97·769	120·599
Total brought forward ...	66·417	68·897	72·981	80·486	92·086	104·324
Weight to be added (in concrete) ...	—	0·258	0·775	1·550	5·683	16·275

Fig. 483.

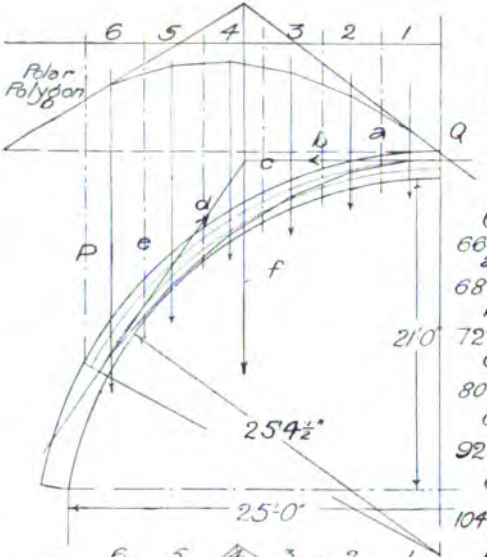
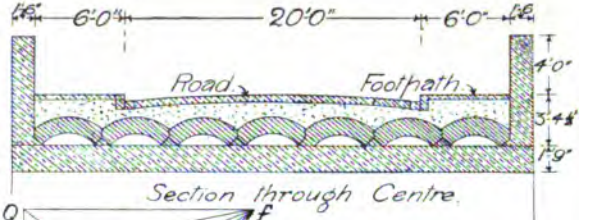


Fig. 484.



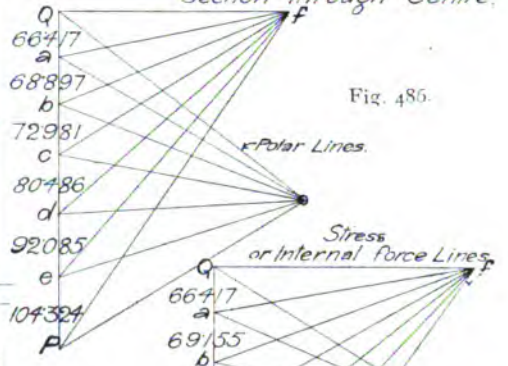


Fig. 486.

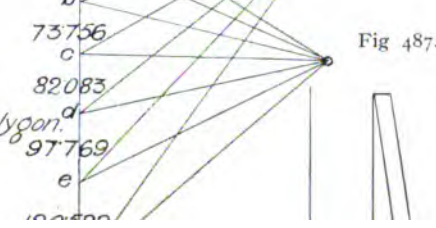


Fig 487.

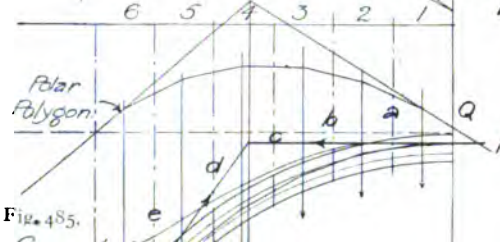


Fig. 485.

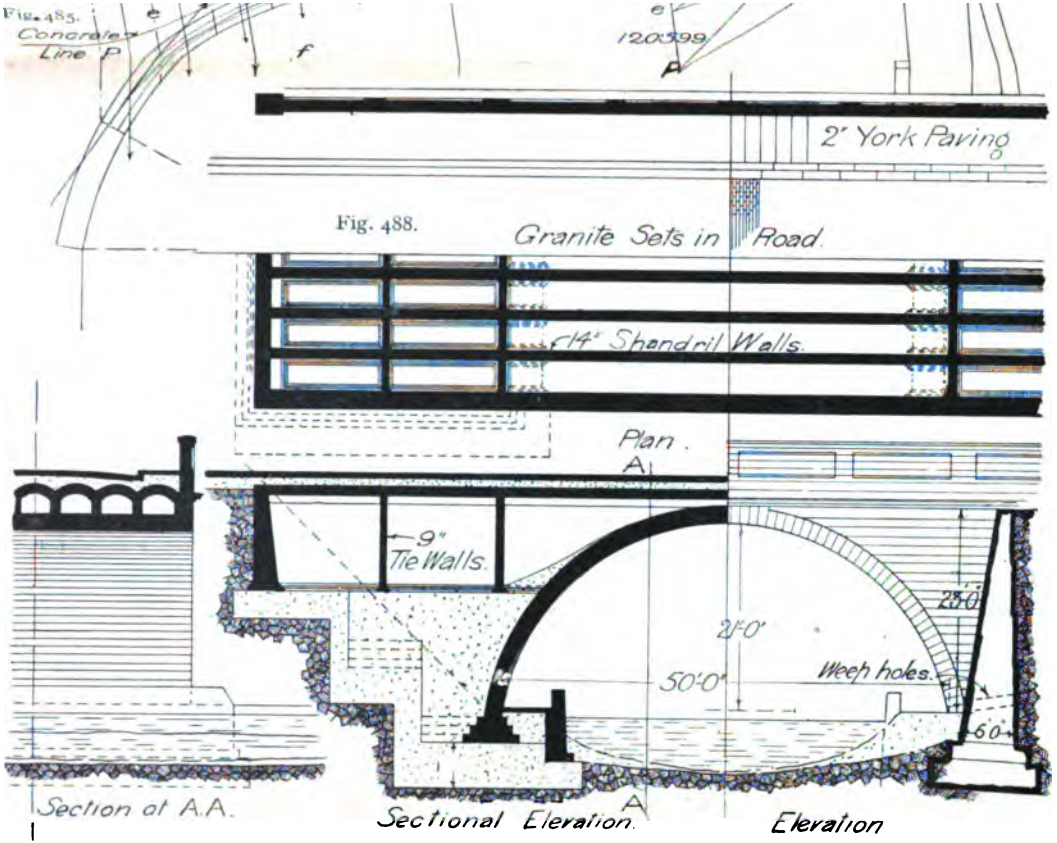


Fig. 489.

Figs. 483—490.

Fig. 490.

[Between pages 226 and 227.

Figures 483 to 490 show working drawings for the construction of the bridge. The bridge may be finished at the banks in one of two ways. If the hollow to be bridged over has high banks, as shown by dotted lines on the left hand side of Figure 490, it would be constructed as shown in section; but if the roadway to be supported by the bridge is elevated by an embankment above the level plane, abutments would be required sufficiently thick to resist the thrust of the arch, and the slopes of the embankment would be supported by retaining wing walls as shown in the Figure 490.

Let a retaining wall be built of granite, 170 lbs. per foot cube, to hold back a mass of clay 120 lbs. per foot cube the angle of repose of which is 45 degrees, the section of retaining wall to be 6 feet at the base, and at the top 2 feet in thickness, with a back approximately vertical. Determine the stability. From what has already been stated

Moment of retaining mass = moment of sliding mass of earth

$$h \times \text{average } t \times l \times w \times \text{leverage} = \left(h \times \frac{9\frac{1}{2}}{2} \times l \times w\right) \tan 22\tfrac{1}{2}^\circ \times \text{leverage}$$

$$h \times \frac{2+6}{2} \times 1 \times 170 \times x = \left(23 \times \frac{19}{4} \times l \times 120\right) 0{\cdot}4142136 \times \frac{h}{3}$$

$$h \times 4 \times 170 \times x = 5430 \times \frac{h}{3}$$

$$680 \times x = 1810$$

$$x = 2{\cdot}66 \text{ ft.} = 2 \text{ ft. } 8 \text{ in. nearly.}$$

The pathway of the vertical through centre of gravity of retaining wall is 3 feet 10 inches from its front face at the base, therefore the resultant of the mass of the retaining wall and the overturning thrust of the earth is 1 foot 2 inches nearly from the front face. The whole pressure may be supposed to be distributed over the base to a thickness of three times the distance of the centre of pressure to the edge about which wall would have a tendency to overturn; in this case this would be 14 in. × 3 = 42 in.

Then the average pressure per square inch of the retaining wall upon the area pressed will be the weight of the retaining wall divided by the area pressed in square inches.

$$\text{Weight of retaining wall} = 23 \times 1 \times \frac{6+2}{2} \times 170 = 15640 \text{ lbs.}$$

$$\text{Area pressed} = 3 \times 14 \times 12 = 504 \text{ square inches}$$

$$\therefore \text{ average pressure per square inch} = \frac{15640}{504} = 31{\cdot}032 \text{ lbs.}$$

$$\therefore \text{ maximum pressure} = 2^{\text{ce}} \text{ average pressure} = 2 \times 31{\cdot}032 = 62{\cdot}064 \text{ lbs.}$$

The lowest crushing value for granites is given by Rankine as 5500 lbs. per square inch, the pressure therefore upon the base is well within the limit of safety.

CHAPTER VIII.

VAULTING.

Classification.—Chambers covered with brick, stone, or concrete are termed vaults, and may be classified under three heads:—

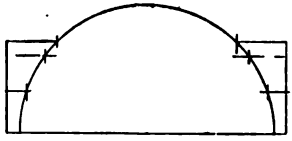
1. Barrel Vaults. 2. Domes. 3. Rib and Panel Vaults.

Barrel Vaults.—A barrel vault consists of a continuous arch, resting upon the side walls of a building, which must be very thick in order to resist the thrust of the vault which is distributed along the whole length of the vault; the walls thus become in effect continuous buttresses. Where barrel vaults intersect each other the line of intersection is known as a groin. To exactly comply with the statical conditions, every part of the groin should lie in the vertical plane; for æsthetic reasons also this condition should apply. Such a straight groin can only be obtained when the radii of the intersecting vaults are equal and their springings are at the same level. In all other cases of intersecting vaults twisted groins will result, as shown in Figures 491 to 494; all such intersections in barrel vaults are sources of weakness, which is very apparent. Figure 494 shows an interior with a barrel vault lit by means of a clerestory formed by smaller barrel vaults intersecting larger. The effect of this, especially where the secondary vaults are large, is to concentrate the pressure of the vaults upon sections of the walls. This is a desirable result, as it enables thinner walls to be built, the points of

concentration only requiring to be fortified by means of cross walls or buttresses.

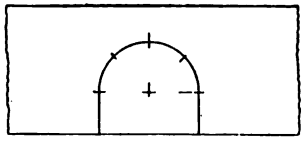
Figures 495 to 500 show the plan, sectional elevation

Fig. 491.

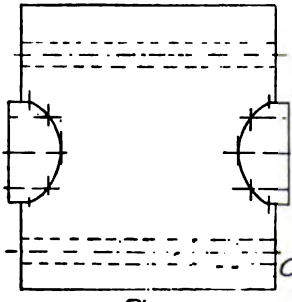


Elevation

Fig. 492.



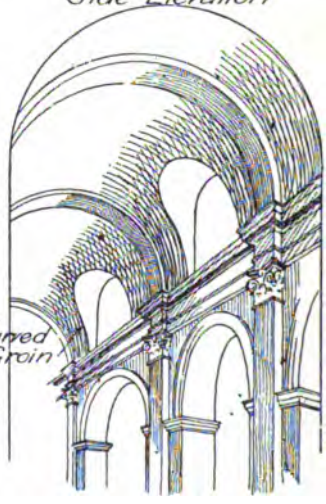
Side Elevation



Plan

Barrel Vault intersected by smaller vault

Fig. 493.



General Internal Sketch Barrel Vault.

Fig. 494.

and details for the construction of two intersecting barrel vaults of equal radii. Figure 496 shows the half plan and intersection of vault looking up. Fig. 498 shows the half plan of the extrados looking down. Figure 495 is the half-sectional elevation showing intrados and groin. Figure

Fig. 495. Fig. 497.

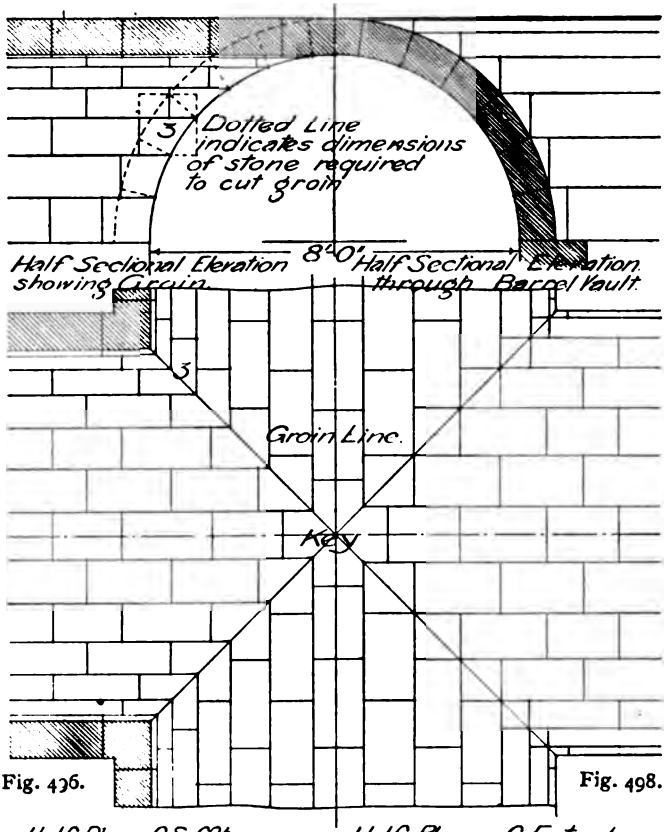


Fig. 496. Fig. 498.

Half Plan of Soffit. Half Plan of Extrados.

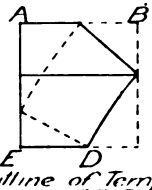
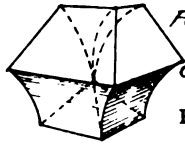


Fig. 499.

Outline of Templet for No 3 Groin.



Perspective view of No 3 Groin Stone.

Fig. 500.

Scale 12 9 6 3 0 1 2 3 4 5 6 7 8 9 of Feet

497 is a sectional elevation of the vault. Figure 499 shows the block of stone out of which No. 3 groin is to be worked, also the templet required. All other groin stones would be projected and worked similarly. Figure 500 is a perspective view of No. 3 groin when finished.

Domes.—A dome is a roof of the form of a semi-spheroid, ellipsoid, or conoid. In its simplest form it is constructed on a wall circular in plan. The dome is more often supported upon walls square or octagonal in plan, but any other regular polygon would apply equally well. If any polygon is inscribed in the great circle of a sphere and planes perpendicular to the surface of the polygon be projected through its sides, these will intersect the sphere in a number of circular sections. If these circular sections form portions of barrel vaults, the usual arrangement as shown in Figures 501 and 502 is obtained.

Types of Domes.—There are three distinct methods of arranging the dome :—1. Where the spheroid is intersected by four square walls, as shown in Figures 501 to 503. In this case the dome appears very flat, a comparatively small portion only projecting above the line of intersection of intercepting walls. 2. In order to obtain greater internal height than in the preceding example let the upper part of the dome above the intersecting walls be considered to be cut off by a horizontal plane resting upon the highest points in the lines of intersection of the walls and dome. This will give a horizontal circle, and upon this a dome of smaller radius than the preceding dome can be constructed, as shown in Figures 504 and 505. The portions of the large lower dome remaining between the four vertical walls and the horizontal plane are known as pendentives, as shown in Figure 506; these practically form projecting corbels constructed so that the square or other polygon may be developed into a circle upon which the smaller or true dome may be supported.

Fig. 501.

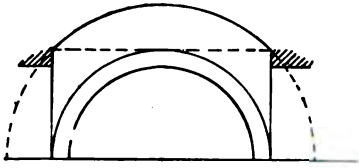
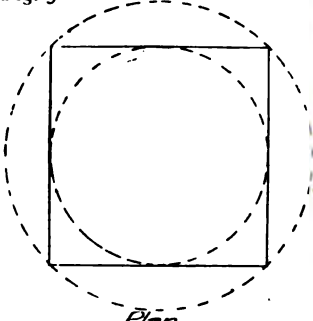
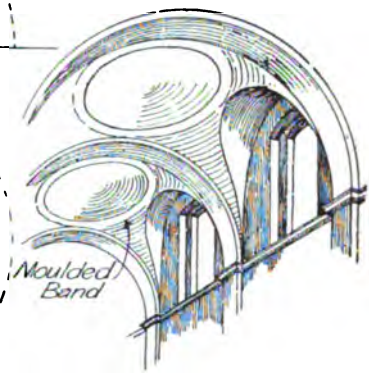


Fig. 502. Elevation



Plan

Fig. 503.



General Sketch.

Fig. 504.

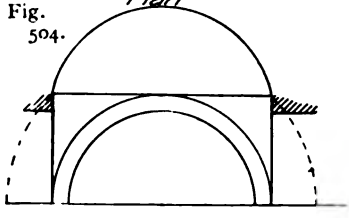


Fig. 505. Elevation

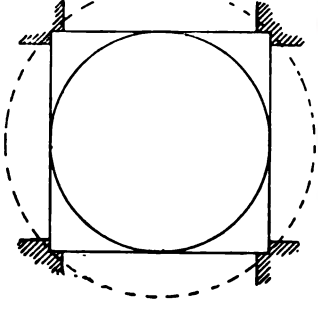
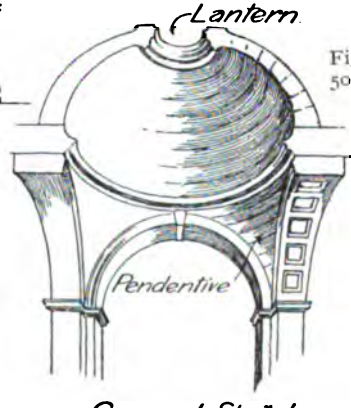


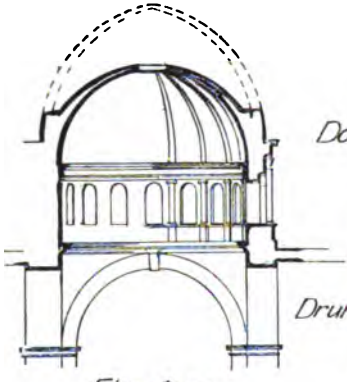
Fig. 506.



General Sketch.
Pendentive Dome.

In the third case, as shown in Figures 507 to 509, in order to obtain still greater internal height the smaller dome

Fig. 507.



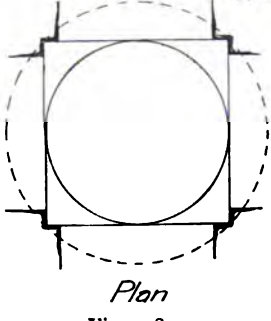


Fig. 508.

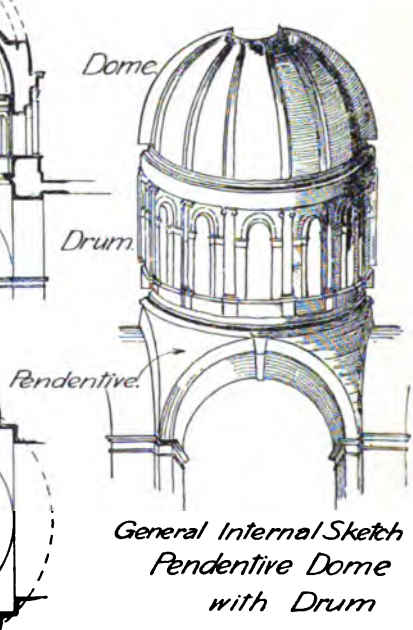


Fig. 509.

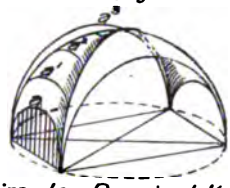
is elevated upon a circular wall, known as the drum, which rests upon the horizontal circle to which attention has been drawn in the preceding example.

General Description.—Domes are usually constructed of

stone or concrete; where of stone they are built in horizontal courses, each of which forms a horizontal arch. Supposing means to be taken to prevent these rings from spreading or opening, then each ring when complete is maintained in equilibrium by the side thrusts of its several voussoirs and the support it receives from the ring immediately below it. Thus in constructing such a dome no centre is required, only temporary supports until the ring being built is complete; owing to this the central portion may be omitted for purposes of lighting, for which lanterns are usually provided. The lower or upper surfaces of the bed joints of each ring if produced would form a cone. There is a tendency for the dome to spread at a point somewhere between the haunch and the base. In the first method the dome is usually sunk well within the walls and there is no fear of spreading; in the second example the wall may be carried up and constructed of a thickness and weight sufficient to resist its outward thrusts, but in the third case this cannot easily be done without a great expenditure of material and the effacement of the dome as an external feature. To prevent spreading in this case a metal band, encircling the dome at some line between the base and the haunch, is employed to tie the structure together. In many of the large types of domical structures, two domes are employed, an internal and an external dome; this is done to gain effect from both the interior and the exterior. A very tall dome internally presents a cavernous effect and cannot be properly viewed from the inside. A low dome such as would present a good appearance internally would from the exterior appear stunted.

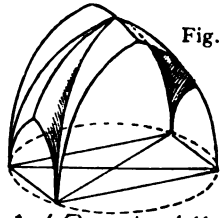
Domes are frequently now constructed of concrete, which has become possible from an economical point of view since the introduction of such a powerful matrix as Portland cement. They are constructed upon a wood centre, upon which the concrete is deposited in regular

Fig. 510.

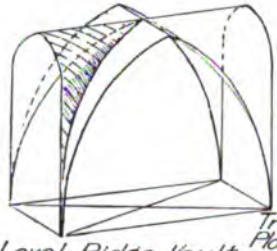


Circular Domical Vault.

Fig. 511.



Pointed Domical Vault



Level Ridge Vault

Fig. 512.

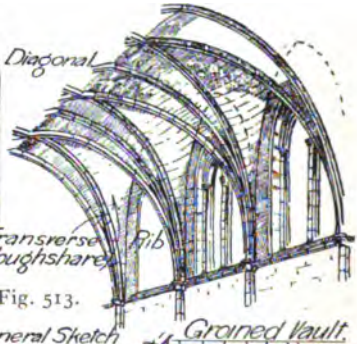
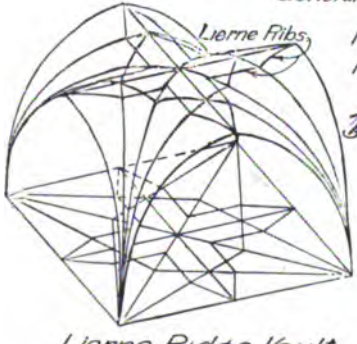


Fig. 513.

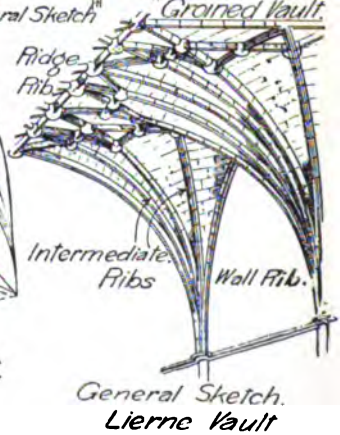
General Sketch



Lierne Ridge Vault.

Fig. 514.

Groined Vault



General Sketch.

Lierne Vault

Fig. 515.

horizontal rings. In no case should iron ribs be inserted in the concrete, as the unequal expansion and contraction tends to fracture.

Rib and Panel Vaults.—In the reference to the barrel vaults it was pointed out that the groin was a line of weakness, and where bent was an apparent defect; to remedy which efforts were made to construct vaults of varying radii whose line of intersection should be in a vertical plane. If two great semi-circles of a sphere intersecting at their crowning points, and their extremities are distant from each other an amount equal to the spans of the vaults to be intersected, then let these extremities in plan be joined by lines and upon these latter erect semi-circles. If these semi-circular surfaces be imagined to be moved upward, as shown in Figure 510, along the great semi-circles, always keeping them in a vertical position, curved surfaces will be generated that will intersect in the great semi-circles as shown in Figure 510. If these great semi-circles are constructed as two intersecting stone arches they will emphasize the groin, and will form support for the vaulted surfaces. A form of vault or arch that will exert a less horizontal thrust upon the walls or supports is the pointed arch or vault. This form of vault was at first used as a barrel vault, and at a later date for the rib and panel vaults, for the purpose of reducing the horizontal thrust. Figure 511 shows the form of a pointed groined vault. This and the preceding example are known as domical vaults.

Figures 516 to 520 show the working drawings for a domical vault. The ribs of this vault, as shown in Figures 516 and 517, all form segments of similar curves. As all the ribs are of varying spans and segments of similar circles the apex of each system will occur at different heights, and as the panelling is all built concave on the under surface the ridge lines joining the apices will be curved also.

In order that the panels may rest upon the ribs uniformly

at all points, it is necessary that the face edges, as shown in Figure 517, of adjacent ribs shall separate at the same height. It will be noted that in an oblong vault, as shown in Figure 516, the diagonal and transverse ribs intersect at a higher level than the diagonal and wall ribs, but the highest point at which all the ribs separate is taken, and all the ribs constructed as portions of similar arcs up to that point; by so doing all the mouldings and face edges will intersect uniformly. To obtain this height draw the ribs in plan, from the point where the sides intersect erect a projector to cut the face edge in elevation, this will be the required height. At this height, K, the skewbacks in all cases are formed, and if the ribs are of varying curves, the curves commence to differ at this point; up to this height in which all the ribs are combined, the bed joints are made horizontal. Figure 520 shows the section of the rib employed, this would be cut out of zinc and used as the templet for cutting the arch rib stones; for obtaining the templets for cutting the corbel courses, Figures 518 and 519, project from the elevation on to the plan of the transverse ribs, Figure 518 and 519, the increased lengths of the members due to these joints not being normals to the curves. As all the ribs are portions of similar segments, these lines may be swung round from the centre, O, till they cut the centre line of each rib, and thus the projections of each member may be drawn.

The Panelled Surface.—The exact form of the panelled surface is immaterial provided the under surface is concave, the direction of the bed joints may be parallel to the ridge line, as was the common method employed in France; in England it was usual to place the bed joints at some angle to the ribs on which they rested, generally about right angles to the line bisecting the lower angle of the panel; it is important whichever way the courses are laid that they should be concave on their under surfaces, so that each

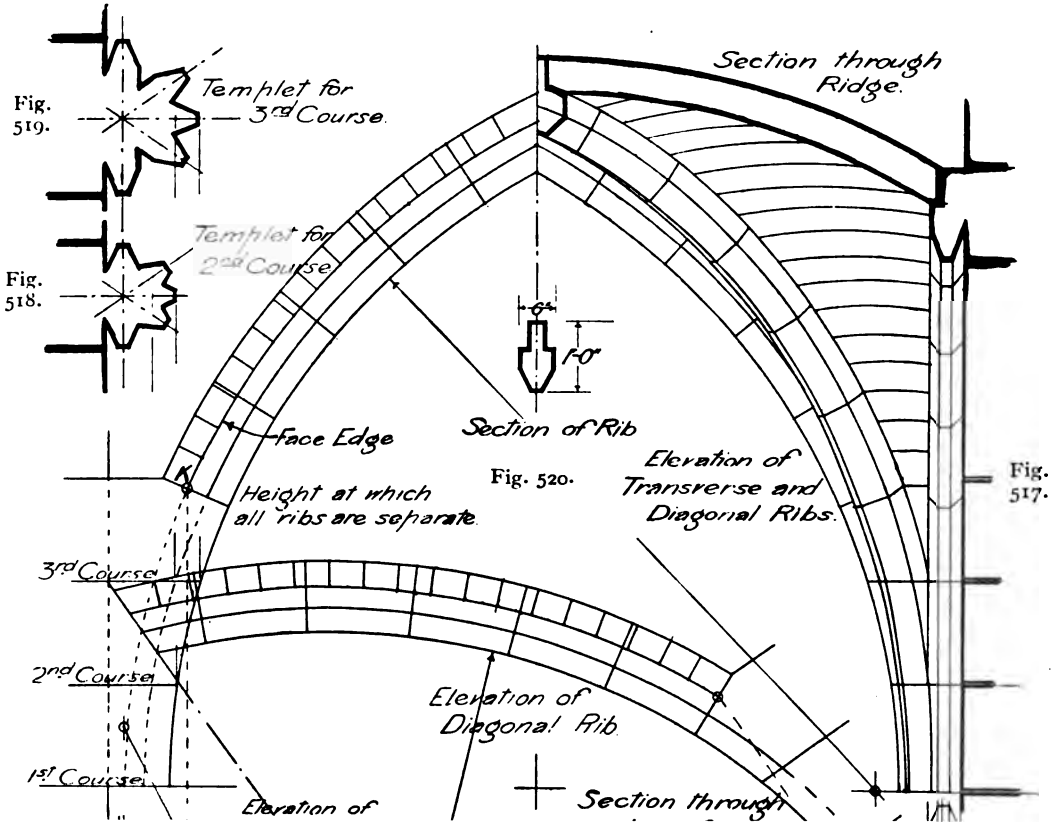


Fig. 519.
Templet for 3rd Course.
Fig. 518.
Templet for 2nd Course.
Section through Ridge.
6"
1'-0"
Section of Rib
Face Edge
Height at which all ribs are separate.
Fig. 520.
Elevation of Transverse and Diagonal Ribs.
Fig. 517.
3rd Course
2nd Course
1st Course
Elevation of Diagonal Rib.
Elevation of
Section through

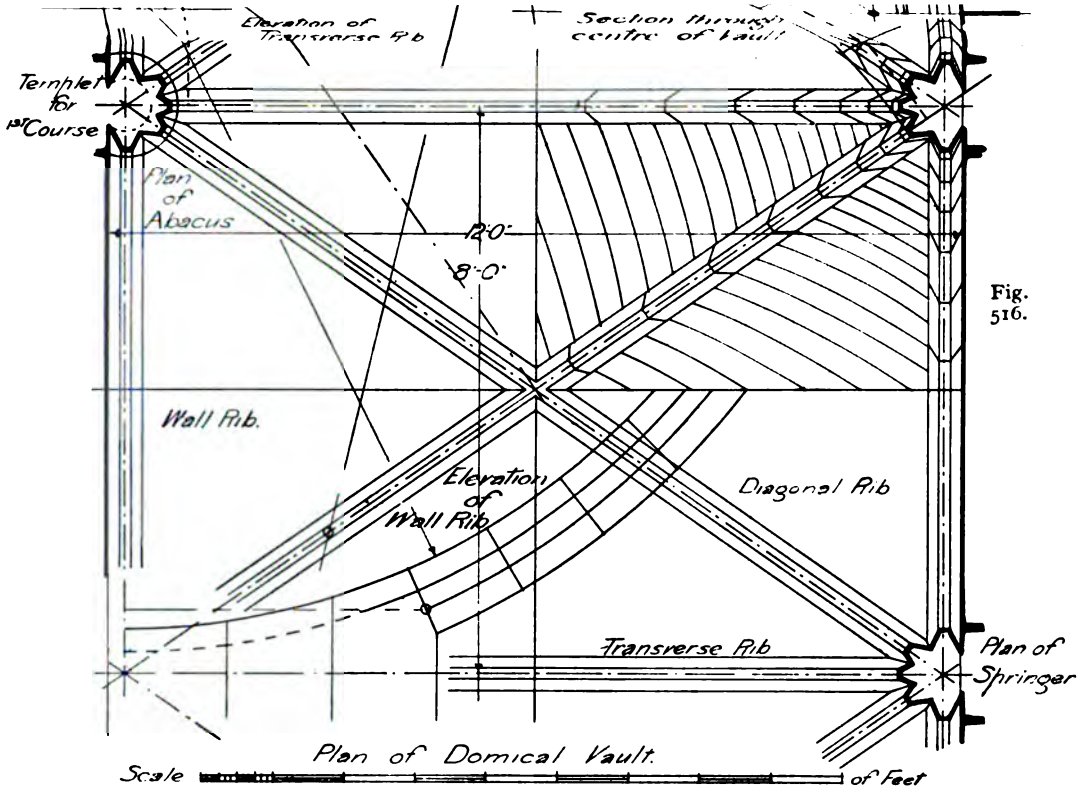


Fig. 516.

[Between pages 238 and 239

course when complete will form an arch and will only require supporting until that particular course is built, and thus the whole surface will not require a special centre for its construction as would be required for a barrel vault.

Level Ridge Vaulting.—The preceding principle understood, general efforts were made to raise the crowns of the intersecting vaults to the same level, until finally the ridge lines were level. In the pointed vaults, no matter what the span, the crown can always be raised to any level required by lengthening the radius; but this, where the intersecting vaults vary much in their span, would give an unsightly lancet-shaped slit for the narrow vault. To remedy this the springing of the narrow vault was raised to the height required, thus causing the panelled surface to lie for a portion of its length in the vertical plane, and giving a twisted surface to the panel, termed a ploughshare from its resemblance to that instrument.

Figures 512 and 513 show a diagram and sketch of a level ridge vault. Figures 521 to 523 show the working drawings for a level ridge vault. Figure 521 shows the plan of one bay with the elevation of the diagonal and wall ribs. Figure 522 shows the elevation of the transverse rib and a half-sectional elevation taken through the ridge of the vault and the position of the ploughshare panel, the diagonal and transverse ribs are struck to the same curve up to the height of the point K, at which point they commence to have a separate existence and from which the arch proper commences; it may be noted that the springing of the wall rib has been raised, the result of which is to form a ploughshare panel. Figure 523 shows the front elevation of the ribs at the springing. Figure 521 shows the method of projecting the joint lines in plan from the elevation of the rib.

The direction of the courses of the filling in or panelling must make an angle with the ridge. The courses are

generally arranged at right angles to the line which bisects the lower angle of the panel.

The reason governing and satisfied by this method of procedure is that it is required that each course when laid shall form an arch in itself. If this be done no centres are required for the panelling, but only temporary supports for each course till they are completed.

Lierne Rib Vaulting.—In the later developments of the rib and panel vaulting there was a tendency to cover large spans; this necessitated the introduction of intermediate ribs between the diagonal and the wall or transverse ribs to strengthen the panelled surfaces. This rendered it imperative to employ ribs at the ridge also. The next stage was to stiffen the groin ribs by means of shorter ribs placed between them; these were arranged to some geometrical pattern, generally a star-shaped figure, and were termed "lierne ribs" from the French word "lier," to bind. To facilitate the setting out and to simplify the construction, the centre plane of these ribs was kept vertical; this rendered it impossible to properly intersect the mouldings at the junction of the ribs, but this difficulty was surmounted by substituting for the intersection a boss of stone, generally carved. Figures 514 and 515 are diagrams showing lierne ribs and a general sketch.

Figures 524 to 526 show the working drawings of a lierne rib vault. Figure 526 gives the plan of the vaulting as seen from below, also elevations and true shapes of the transverse, intermediate, diagonal and lierne ribs. It may be noted that the boss stones at the points of intersection are formed level on their upper surfaces, on this the angles and widths of the projecting arms can be accurately set out. The bevils for all the bed joints for the boss stones can also be obtained from these projections. Figure 525 shows two sections, one at B B showing the section through the transverse rib, wall, and buttress; the other, through

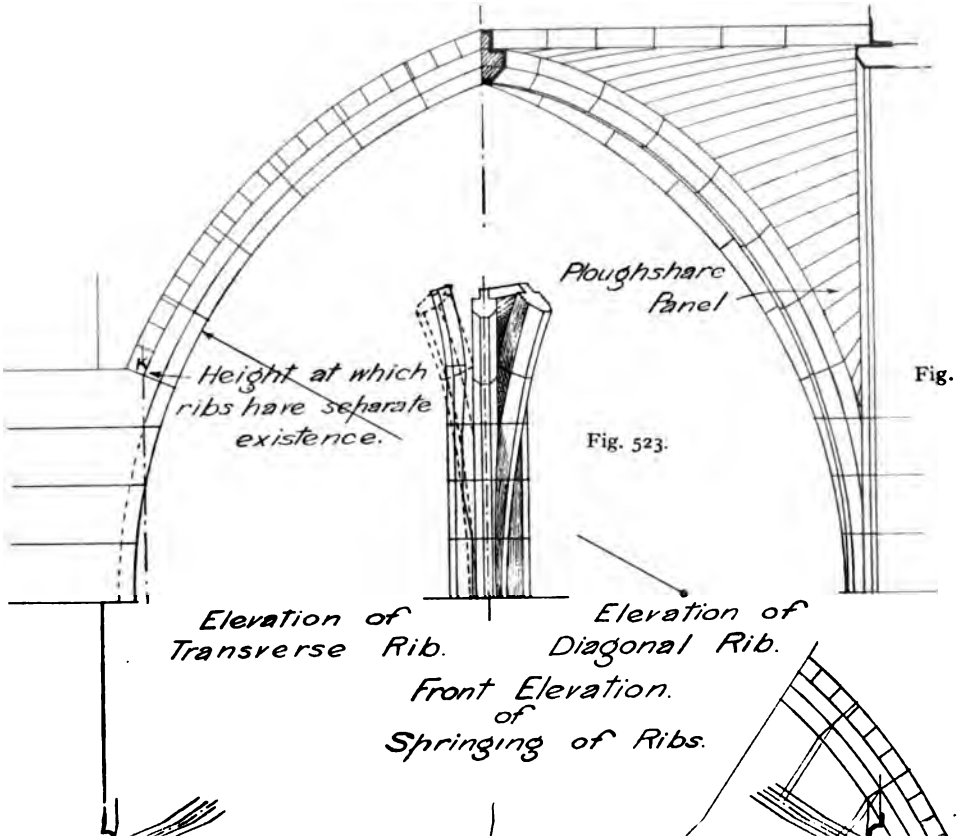


Fig. 522.

Fig. 523.

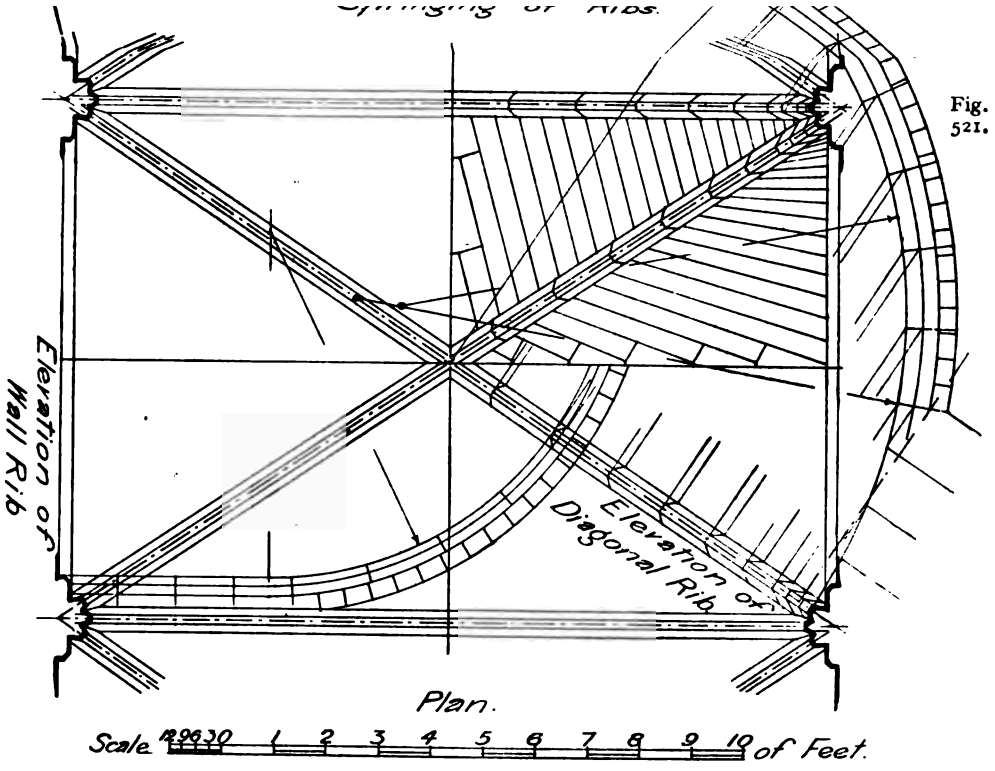


Fig. 521.

Level Ridge Vaulting.

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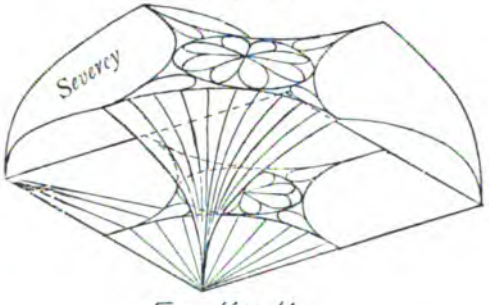
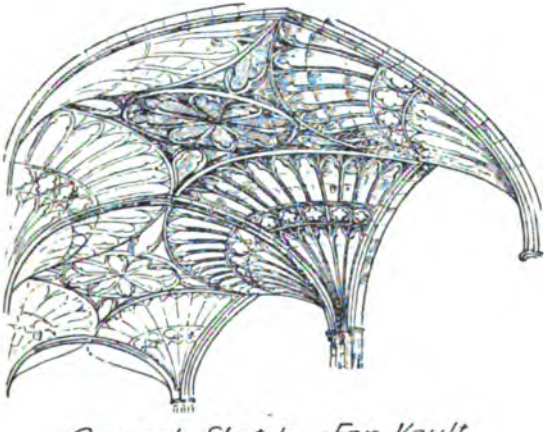
A A, showing the elevation of the vault. Figure 524 shows a section of the rib employed, with the position of the cement joggle.

Fig. 527.



Fan Vault.

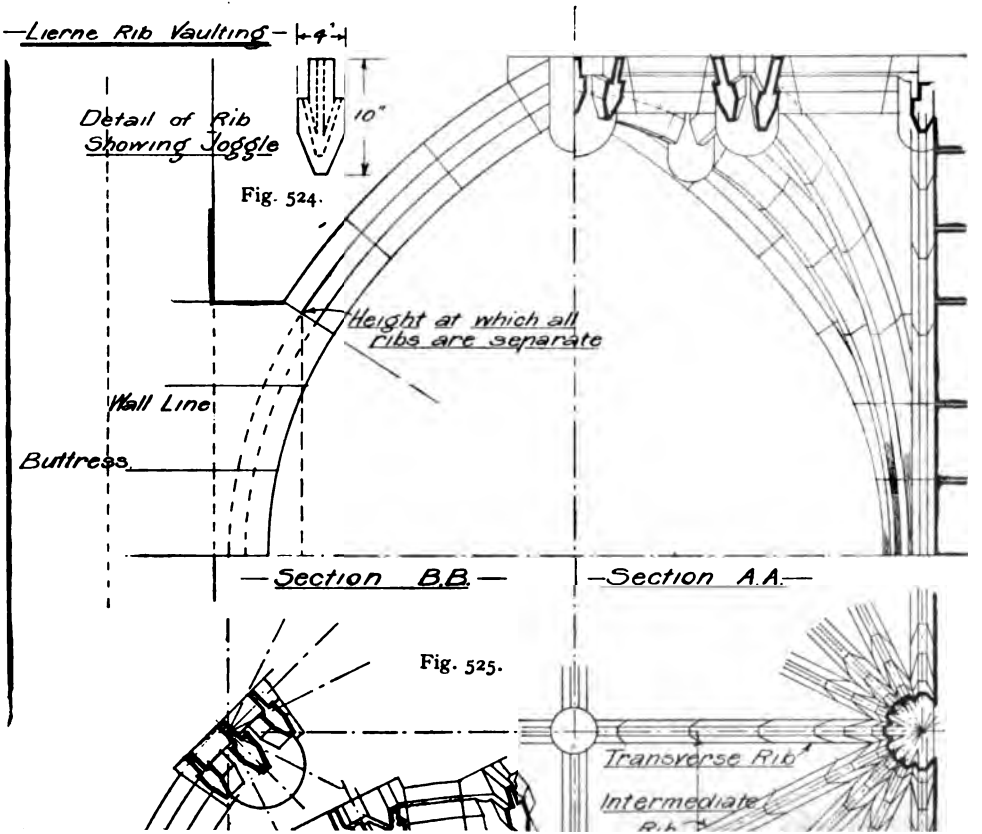


General Sketch Fan Vault.

Fig. 528.

Fan Vaulting.—The tendency of the development of the rib and panel vaults was to increase the number of the intermediate ribs, at the same time to make them lighter,

which led up to constructing every rib as a portion of similar curves springing from the same point, and the ribs having an equal angular distance between them which culminated in the severeys becoming portions of inverted conoids. The intersection of the conoids gave an undulating line, along which a ridge rib was usually formed. The number of ribs was increased to such an extent that in the fully-developed style they ceased to exist as separate members but became merely projections formed by the sinking of the panels. Horizontal ribs, as shown in Figure 527, were formed at intervals in the height of the conoid for decorative purposes and to afford an opportunity of increasing the number of ribs as they approached the ridge. In some instances the ridge ribs were continued through from end to end of the chamber; in others the quadrilateral surface in the centre of the compartment left between the intersecting horizontal ribs was filled in by circular panels or other traceried designs having no reference to the ribs of the conoid, as shown in Figures 527 and 528. The chamber was frequently divided into compartments by transverse arches and each compartment roofed by four inverted quarter conoids.


Lierne Rib Vaulting
4'
10"
Detail of Rib Showing Joggle
Fig. 524.
Height at which all Ribs are separate
Wall Line
Buttress
Section B.B.
Section A.A.
Fig. 525.
Transverse Rib
Intermediate

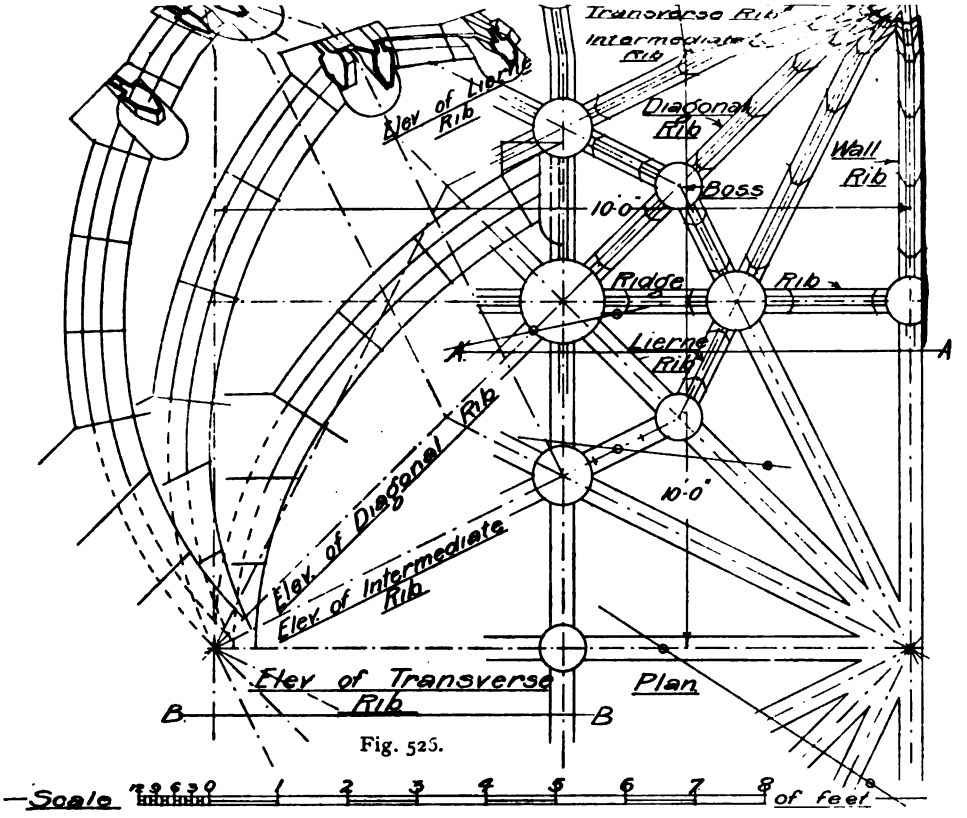


Fig. 525.

[Between pages 242 and 243.

CHAPTER IX.

SKEW ARCHES.

Necessity.—Where it is necessary to have two roads at different levels, one crossing the other at any angle other than a right angle, a skew arch, if in masonry or brickwork, becomes necessary. This differs from the ordinary arch, in that the bed-joints are not parallel to the abutments but are placed as nearly as possible at right angles to the face of the arch, for if they were placed parallel it is apparent that a large portion of the arch would have no abutment on one side and thus would fail. Under these conditions the bed-joints form winding surfaces similar to a screw thread forming a helical coursing surface.

Projection.—A few simple geometrical problems require to be known to understand the construction of a skew arch. Skew arches are invariably formed as portions of a cylinder, and the faces of the arch may be conceived as the projections of sections made by two vertical cutting planes passing through the semi-cylinder at an angle other than 90 degrees to its axis.

It will be necessary to develop the portion of the cylindrical surface between the two cutting planes. Figures 529 and 530 show the method of performing this operation. Figure 529 shows the plan and elevation of the cylinder with the two cutting planes passing through. The elevation of the cylinder is divided into six equal parts, the projections of these points are drawn in plan and intersect

Fig. 531. Fig. 532.

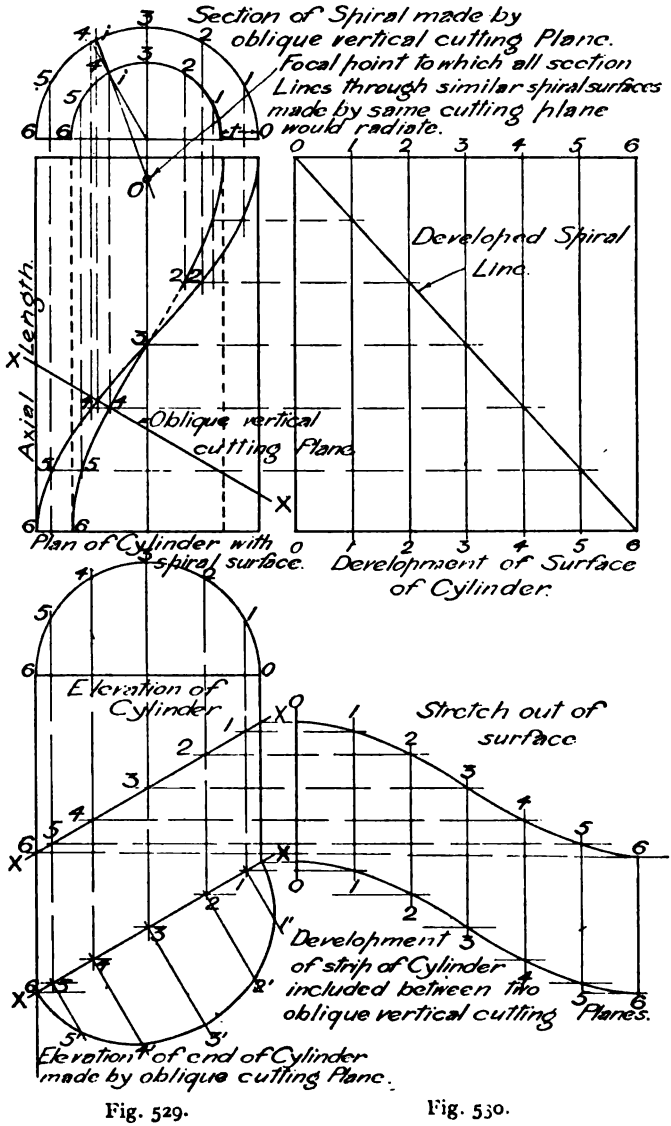


Fig. 529. Fig. 530.

the cutting planes at 0, 1, 2, 3, 4, 5, 6. To obtain the development of the surface between the planes, the surface of the cylinder must be stretched out on a plane surface and the perpendicular distance between 0 and 6 drawn as shown in Figure 530. The stretch out must be divided into six parts to correspond to the divisions on the cylinder; projectors must then be drawn from the points 0, 1, 2, 3, 4, 5, 6 in plan till they intersect the divisions 0, 1, 2, 3, 4, 5, 6, respectively, on the stretched out surface; then, if these points of intersection are joined by lines, the surface between these is the development of the portion of the cylinder between the cutting planes.

Figure 529 shows the method of obtaining the section of the cylinder made by one of the cutting planes.

Where the projections intersect the cutting planes in plan, erect perpendiculars, and measure the heights of 1, 2, 3, 4, 5, from the elevation and mark them off respectively on the perpendiculars; join these points, and the resulting elliptical curve is the elevation of the cylinder seen at right angles to the cutting plane.

Helical Surface.—Helical surfaces similar to helical coursing surfaces and helical heading surfaces may be drawn as shown in Figures 531 and 532. Figure 531 shows the plan and elevation of a cylinder with a thickness *t*. Divide the two cylindrical surfaces into six equal parts, 0, 1, 2, 3, 4, 5, 6, and draw the projections of these points in plan; by the side of the plan draw Figure 532, which may be the developed surface of the inner or outer cylinder, in this case the outer cylinder. Divide this surface into six equal strips and cut off from it a length equal to half of a complete revolution and known as the axial length, as shown in Figure 531. Draw a diagonal from 0 to 6, Figure 532; this will be a developed spiral line; from the points of intersection of this diagonal and the projectors 0, 1, 2, 3, 4, 5, 6, draw projectors to cut the corresponding projectors in plan; join

these points in plan, and a spiral or helical surface is depicted. In Figure 531 the plan of a vertical cutting plane, X X, is shown oblique to the axis of cylinder. This cuts the helical surface in the points I I. Project these points to the elevation till they cut the inner and outer cylinders respectively, join I′ I′ in elevation and produce till it cuts the centre line in O, this point, O, is the centre from which all the chords of all face-joints of similar helical surfaces cut by the same cutting plane would radiate.

Face-Joints.—To determine the direction of face-joints in elevation taken parallel to face of arch. These face-joints will all be parts of curves, owing to the face of arch cutting the spirals at an angle other than at right angles to axis of cylinder. It will be noted that the chords of these small arcs will all radiate from some point, N, Figure 535, some distance below the springing of arch. The distance M N will increase with the angle of obliquity of bridge with road. This distance M N $=$ r cot θ tan α, or (r $+$ e) cot θ tan ϕ. This may be proven as follows. From Figure 534 draw Z P, which $=$ the tangent of α.

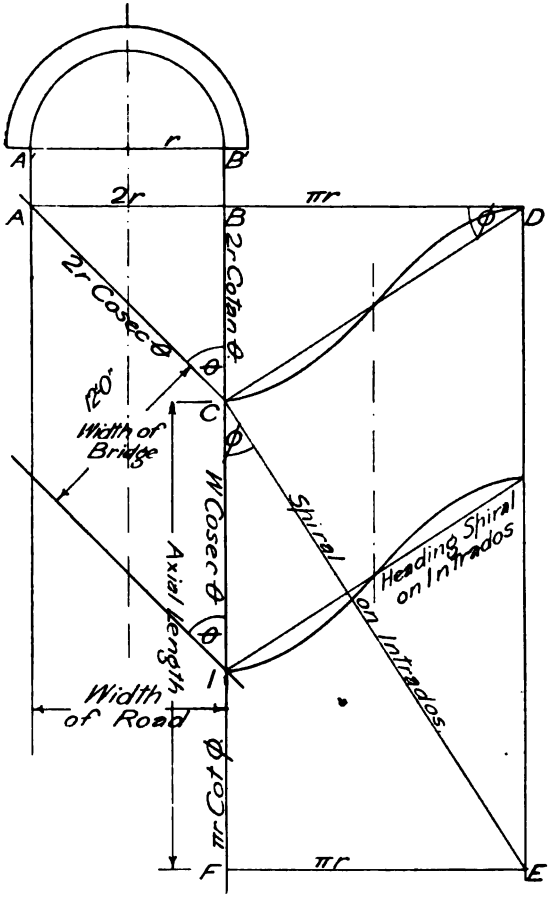
$$XZ = e \operatorname{cosec} \theta$$
$$YZ = e \cot \theta$$
$$\frac{ZP}{YZ} = \tan \alpha$$
$$ZP = e \operatorname{cosec} \theta \tan \alpha$$

Figure 535 represents the elevation of arch parallel to face. Let the values of Z X P be taken from Figure 534. From point P draw P X and produce it to cut M N at N, then M N will equal the distance below the springing of arch from which all the face-joints must be drawn.

$$XZ : PZ :: XM : MN$$
$$MN = \frac{PZ \times XM}{XZ}$$

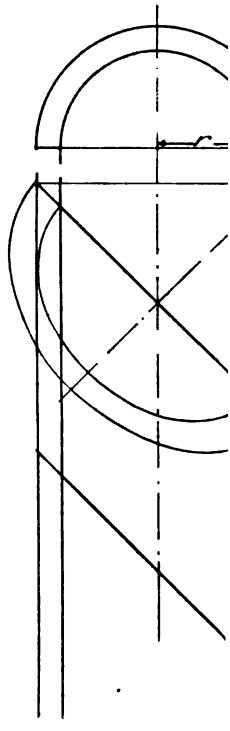
Computation.—For the purposes of constructing skew arches it is better to determine the dimensions by calcula-

Fig. 533.



Development of Intrados and coursing and heading Spirals

Fig 534.



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534.

Fig. 535.

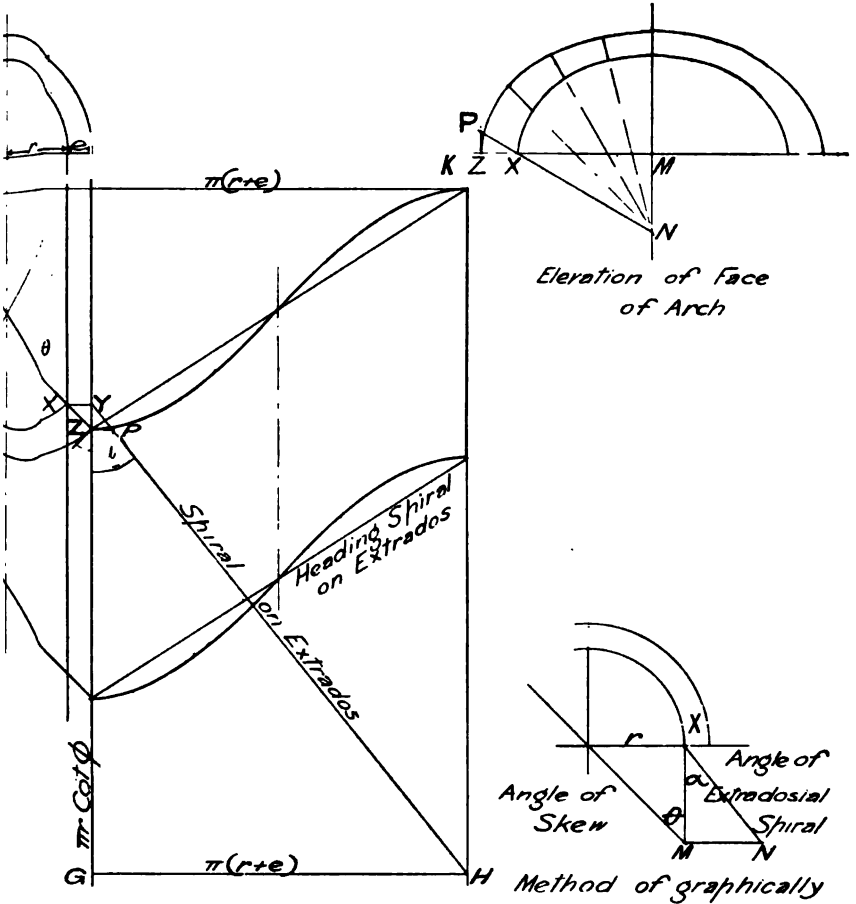


Fig. 536.

[Between pages 246 and 247.

tions than from drawings, as any small inaccuracy in drawing would amount to an error of appreciable quantity if measured from a drawing of small scale, as all such cases must of necessity be drawn. The necessary dimensions may be computed mathematically for all parts with accuracy. Figures 533 to 536 are explanatory of the required calculations.

Figure 533 shows plan and elevation of a semi-circular arch crossed by a road at an angle of θ with its axis.

Let r = radius then $2r$ = the span
θ = angle of obliquity of bridge with centre line of road
$2r \operatorname{cosec} \theta$ = the oblique span
$2r \cot \theta$ = the length of obliquity of arch
πr = the width of the development of intrados
CD = the development of heading spiral
ϕ = angle of heading spiral with the developed width of the intrados
$\tan \phi = 2r \cot \theta$ divided by πr
W = width of bridge

Let a line be drawn at right angles to the heading spiral (C D), cutting D E at E; this is the development of the spiral of the intrados. At E draw a line at right angles to D E, to cut B C produced in F.

Then F C is the axial length of the spiral of intrados and $= \pi$ r $\cot \phi$.

C I = length of impost and $=$ W $\operatorname{cosec} \theta$.

Figure 534 shows plan and elevation of same arch with the development of extrados.

Let E = thickness of the arch
LK = width of the development of extrados and $= \pi (r + e)$
ZK = development of heading spiral on extrados
YG = CF = the axial length
YH = the spiral of extrados
α = angle of spiral on extrados with the impost and its value

$$= \tan \alpha = \frac{\pi (r + e)}{\pi r \cot \theta}$$

that is, $\dfrac{r + e}{r \cot \theta}$

Fig. 537. Fig. 538.

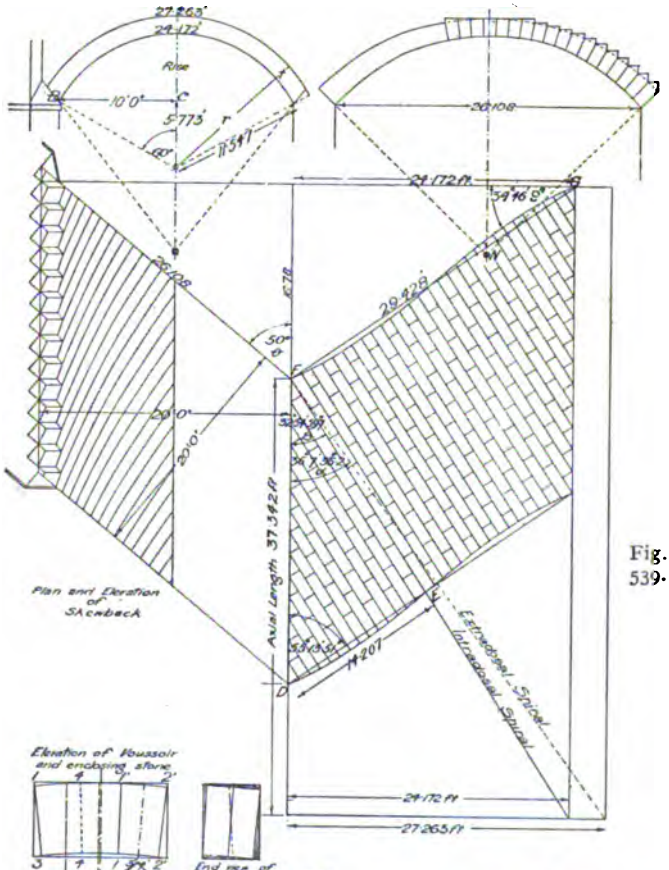


Fig. 539.

Fig. 540A. Fig. 540.

The distance M N may be determined graphically as shown in Figure 536. Draw the elevation of the semi-cylinder, and from the centre draw a line passing through the axis, making the angle θ (that is, the angle of obliquity) with the same, till it cuts the impost line in M; at the point M set out a line M N at right angles to the impost. From the point X draw a line X N, making the angle α (that is, the angle of extradosial spiral) with X M, cutting the line M N in N; then the line M N equals the distance below the centre M of the point N, to which the chords of all the face-joints will radiate.

The difference between ϕ and α equals the angle of the twist for working the bed-joints, the actual values can be obtained for any particular length of stone by the formula

$$\frac{x}{l} = \tan \delta$$

$$x = l \tan \delta$$

Let x = the amount of twist for any given length
l = length of stone
δ = difference between ϕ and α, the angles of coursing spirals between intrados and extrados.

Segmental Arch.—Let it be required to construct a bridge 20 feet wide over a road with a width of 20 feet, the faces of the bridge making an angle of 50 degrees with the centre line of the road. The arch to be segmental with an arc subtending an angle of 120 degrees, depth of arch to be 1 foot 6 inches.

First determine the radius r; then, from Figure 537, $\frac{c}{a}$ = cosec 60 degrees.

$$\text{therefore } c = a \operatorname{cosec} 60^\circ$$
$$c = 10 \times 1{\cdot}1547$$
$$c = 11{\cdot}547 = \text{radius of arch.}$$

Then determine the rise—

$$\frac{b}{a} = \cot 60^\circ$$

$$b = a \cot 60^\circ$$
$$b = 10 \times \cdot 57735$$
$$b = 5\cdot 7735$$
$$= \text{rise} = c - b = 11\cdot 547 - 5\cdot 7735 = 5\cdot 7735$$
$$\text{The oblique span} = s \operatorname{cosec} \theta$$
$$= 20 \operatorname{cosec} 50^\circ$$
$$= 20 \times 1\cdot 3054$$
$$= 26\cdot 108.$$
$$\text{The obliquity of arch} = s \cot \phi$$
$$= 20 \cot 50^\circ$$
$$= 20 \times \cdot 839$$
$$= 16\cdot 78.$$

Length of intrados equals radius multiplied by value of arc of 120°; from the tables this will be $11\cdot 547 \times 2\cdot 0943 = 24\cdot 172$. Length of extrados is obtained in a similar manner. Then the radius of the extrados will $= (r + t)$, that $= 11\cdot 547 + 1\cdot 5 = 13\cdot 047$; then the length of the arc $= 13\cdot 047 \times 2\cdot 0943 = 27\cdot 263$.

The Angle of Coursing Spiral.

$$\tan \phi = \frac{\text{obliquity of arch}}{\text{length of arc}}$$
$$= \frac{16\cdot 78}{24\cdot 172}$$
$$\text{therefore } \phi = 34^\circ\ 46'\ 9''.$$
$$\text{Length of heading spiral will} = \frac{\text{heading spiral}}{\text{obliquity of arch}} = \operatorname{cosec} \phi$$
$$\text{heading spiral} = \text{obliquity of arch} \operatorname{cosec} \phi$$
$$= 16\cdot 78 \times \operatorname{cosec} 34^\circ\ 46'\ 9''$$
$$= \log 16\cdot 78 \quad 1\cdot 2247920$$
$$\text{L} \log \operatorname{cosec} 34^\circ\ 46'\ 9'' \quad \underline{10\cdot 2439729}$$
$$11\cdot 4687649$$
$$29\cdot 428.$$

Let the number of voussoirs be, say, 29.

The thickness of the voussoirs (the heading spiral ÷ 29) $= \frac{29\cdot 428}{29} = 1\cdot 0148$ feet.

The angle of intradosial spiral ϕ, which should theoretically be at right angles to the heading spiral, must be modified in order that it may correctly intersect the

face-joint on opposite face of arch as each set of face-joints must be similar in elevation. Let the intradosial spiral intersect the fifteenth bed-joint (that is, 14 × 1·0148) which = 14·2072 feet from springing.

The intradosial angle now altered from ϕ to β, in the triangle DEF, figure 539,

$$D = 55^\circ\ 13'\ 51''$$
$$E + F \text{ will} = 180^\circ - 55^\circ\ 13'\ 51'' = 124^\circ\ 46'\ 9''$$
$$\text{and } \frac{\tan \frac{E - F}{2}}{} = \frac{e - f}{e + f} \cot \frac{D}{2} = \frac{11{\cdot}901}{40{\cdot}315} \times \cot 27^\circ\ 36'\ 55{\cdot}5''$$
$$\frac{E - F}{2} = 29^\circ\ 28'\ 4{\cdot}8''$$
$$E - F = 58^\circ\ 56'\ 9{\cdot}6''$$
$$E + F = 124^\circ\ 46'\ 9''$$
$$2E = 183^\circ\ 42'\ 18{\cdot}6''$$
$$E = 91^\circ\ 51'\ 9{\cdot}3''$$
$$2F = 65^\circ\ 49'\ 59{\cdot}4''$$
$$F = 32^\circ\ 54'\ 59{\cdot}7''$$

therefore intradosial angle $\beta = 32^\circ\ 54'\ 59{\cdot}7''$.

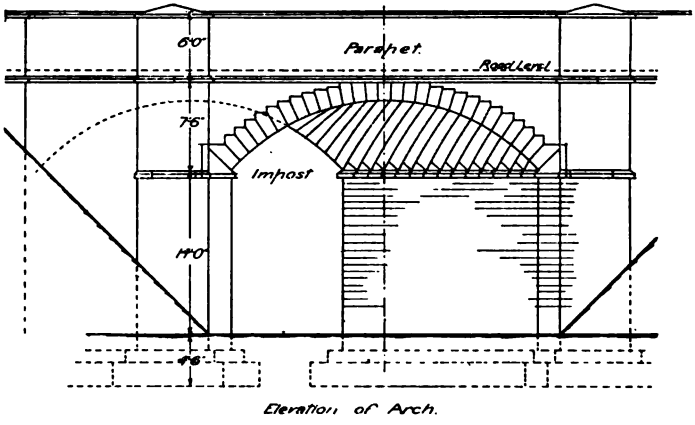
Distance of the point N, towards which the chords of all the face joints converge, from M will equal—

$$(r + t) \cot \theta \tan \beta$$
$$(11{\cdot}547 + 1{\cdot}5) \cot 50^\circ \times \tan 32^\circ\ 54'\ 59{\cdot}7''$$
$$\log 13{\cdot}047 = 1{\cdot}1155107$$
$$L \log \cot 50^\circ = 9{\cdot}9238135$$
$$L \log \tan 32^\circ\ 54'\ 59{\cdot}7'' = \underline{9{\cdot}8111142}$$
$$20{\cdot}8504384$$
$$Mn = 7{\cdot}0866 \text{ feet.}$$

To determine the axial length:

$$\frac{\text{Axial length}}{\text{length of arc}} = \cot \beta$$
$$\text{Axial length} = \text{length of arc} \times \cot \beta$$
$$= 24{\cdot}172 \times \cot 32^\circ\ 54'\ 59{\cdot}7''$$
$$\log 24{\cdot}172 \quad 1{\cdot}3833126$$
$$L \log \cot 32^\circ\ 54'\ 59{\cdot}7'' \quad \underline{10{\cdot}1888858}$$
$$11{\cdot}5721984$$
$$37{\cdot}342$$
$$\text{Axial length} = 37{\cdot}342 \text{ feet.}$$

Fig. 541.



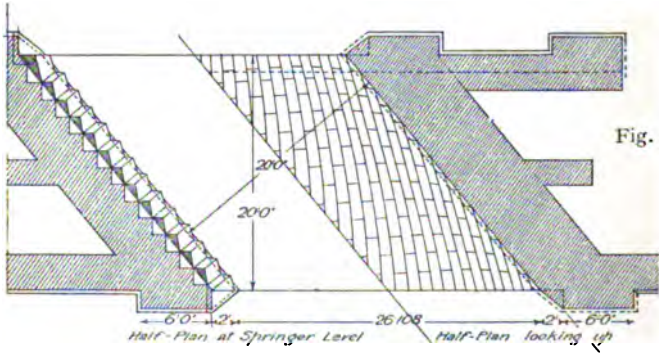


Fig. 542

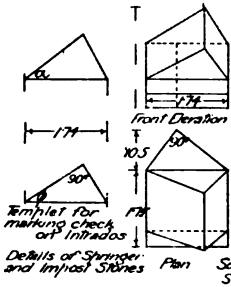


Fig. 543.

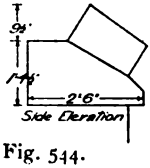


Fig. 544.

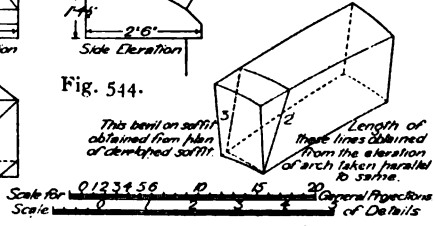


Fig. 545.

To determine the extradosial angle α.

$$\frac{\text{length of extrados}}{\text{axial length}} = \tan \alpha$$

$$\frac{27{\cdot}263}{37{\cdot}342} = \tan \alpha$$

$$\log 27{\cdot}263 \quad 1{\cdot}4355736$$

$$\log 37{\cdot}342 \quad \underline{1{\cdot}5721984}$$

$$\bar{1}{\cdot}8633752$$

$$L \tan \alpha \; 10 + 1{\cdot}8633752 = 9{\cdot}8633752$$

$$\alpha = 36^\circ\ 7'\ 35{\cdot}2''.$$

To determine the angle of twist or δ.

δ or the angle of twist = extradosial angle − intradosial angle
δ or the angle of twist = $36^\circ\ 7'\ 35{\cdot}2'' - 32^\circ\ 54'\ 59{\cdot}7''$
δ or the angle of twist = $3^\circ\ 12'\ 35{\cdot}5''$.

To determine the twist for a stone of given length.

Let X = the twist in any given length and l = the length = $3'\ 0''$

$$\frac{X}{l} = \tan \delta$$

$$X = l \tan \delta$$

$$X = 3 \tan 3^\circ\ 12'\ 35{\cdot}5''$$

$$\log 3 = 0{\cdot}4771213$$

$$L \tan 3^\circ\ 12'\ 35{\cdot}5'' = \underline{8{\cdot}7488168}$$

$$9{\cdot}2259381$$

$$10$$

$$\bar{1}{\cdot}2259381$$

$$\cdot 16824 \text{ feet}$$

$\therefore$ twist for stone $3'\ 0''$ in length = 2·018 inches.

Projections of the Arch.—Figure 538 is an elevation of the face of the arch drawn parallel to the face, showing the arrangement of the face-joints and the true lengths of the bed-joints on face; these are necessary in order to cut the face of the quoin face stones. Figure 541 shows elevation of bridge parallel to the face of the arch. It may be noted that the quoin stones of the face of the arch are arranged with horizontal stepped joints: this is rendered

necessary, particularly in arches of great obliquity, as otherwise there is a tendency for the spandril to slip off the arch. In brick arches the spandril should be tied back towards the centre of the arch with iron cramps, to neutralise this tendency. Figure 542 shows the plan of the arch. One side is a half plan looking up at the soffit, the other half is a plan at the springer level showing the arrangement of the impost and the springer stones. It should be noticed that the backs of the springing stones are worked in steps, so that they may have an abutment normal to the pressure of the arch.

Cutting of Coursing Stones.—Figure 540 shows the method of producing and applying the face moulds for cutting the coursing stones. Figure 540A shows the plan and elevation of a coursing stone looking parallel to the centre line of the road under the bridge. It also shows the projections of the rectangular block of stone that would contain the coursing stone. The extradosial and intradosial surfaces are projected till they cut the sides of the enclosing block. The form thus delineated is the face mould to be applied to the side of the stone, and is shown in the auxiliary elevation in Figure 540A. The ends of the coursing stone are produced till they cut the ends of the enclosing stone, and in a similar manner the form delineated is the templet for the end of the stone as shown in the end view, Figure 540A. The end view shows the bevil (calculated from the angle of twist) applied, and the templet for the end. Figure 540 is an insometric view of the block of stone, showing the end and side face moulds in position. To work the stone it is necessary to remove the superfluous stone shown by shaded lines, this will form the intradosial and extradosial surfaces. To form the bed-joints two parallel strips of zinc are required, one the width of the extrados of the stone, the other the width of the intrados, these are placed one on the bottom and top respectively and so that their

edges coincide with the angles of the ends of the templets. A line must be drawn along each edge, and on the removal of the superfluous stone the bed-joints will be formed.

Face Stones.—Figure 545 is an isometric view of a coursing stone to be used at the quoins. To obtain the lines to give the face of the stone, proceed as follows: (1) mark the soffit, the bevil for which can be obtained from the developed soffit; and from the extremities of the line thus obtained draw the side joints, the lengths for which can be obtained from the elevation of the arch, Figure 538. Join these lines on the extrados and remove the superfluous stone, this will give the face for the first voussoir from the springing.

Springer Stones.—Figure 543 shows the templets for marking the check on the springer stones. The templet for intrados is obtained as follows: There are fifteen stones in the impost, the length being 26·1008 feet $\div$ 15 = 1·74 feet, this gives the length of the base line of the templet. From one extremity set up a line making an angle ϕ with base, from the other extremity set up a line making a right angle with the last line drawn, the triangle thus obtained will be the templet of the intrados. The templet for the extrados will have a similar length of base, draw this base line immediately over the preceding base line and draw a line from the apex of the first triangle till it intersects a line drawn with angle α from that end of the base which corresponds with the angle ϕ of the first triangle, as shown in Figure 543. Figure 544 shows plan, elevation and section of a springer stone fully dimensioned.

CHAPTER X.

FLUES, FIREPLACES AND TALL CHIMNEYS

Chimney Stacks.—Enclosed channels, formed usually in brickwork, to discharge (1) smoke, are termed smoke flues; (2) vitiated atmosphere, are termed foul air flues; a construction containing one or more vertical flues being known as a chimney stack.

Theory.—Air upon being heated ascends, its velocity being determined by the well-known kinematical formula $V^2 = 2gh$, and if the value of g be taken as 32, $V = 8\sqrt{h}$, and $h = Ht \times \cdot 002$, where H equals the height of column of heated air in feet, and t the excess in degrees Fahr. of column of heated air over external air.

Smoky Flues.—Theory points out that an increased velocity may be obtained by increasing the height or raising the temperature, and the greater the upward velocity the less will be the probability of a down draught, the latter causing what is known as a smoky chimney, and it suggests that a flue with a small volume of air to rarify, with a comparatively great height, is more effective than an equal volume in a flue with a less height.

Prevention of Down Draughts.—To prevent down draughts no external chimney opening for the discharging of smoke should have a lower level than any other similar flue exit in close proximity, and it is in addition preferable for this

opening to be about 3 feet above any adjacent ridges or walls.

Care taken in this matter would to a large extent render unnecessary cowls and other expedients for the so-called "cure of smoky chimneys."

Flues.—The flues should be built with at least one bend with an internal angle of not less than 130 degrees. They

Fig. 546.

Fig. 547.

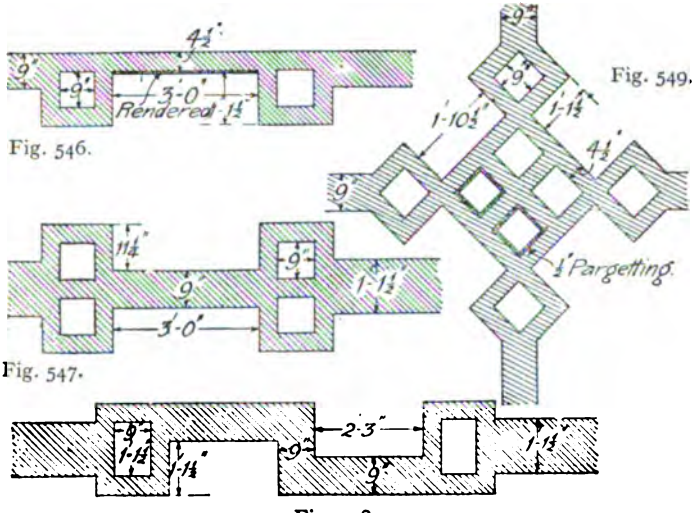


Fig. 549.

Fig. 548.

must be gradual and easy, so as to offer a minimum resistance to the up current. Gusts of wind and down draughts are retarded by the bends in the flues; the same sectional area should be kept throughout till near the exit, when a small contraction in area is conducive to an increased velocity.

Classification of Smoke Flues.—The plans of chimneys may be arranged in three ways, viz.: (*a*) Back to back, as shown in Figure 547; (*b*) side by side, or interlacing; (*c*) diagonally.

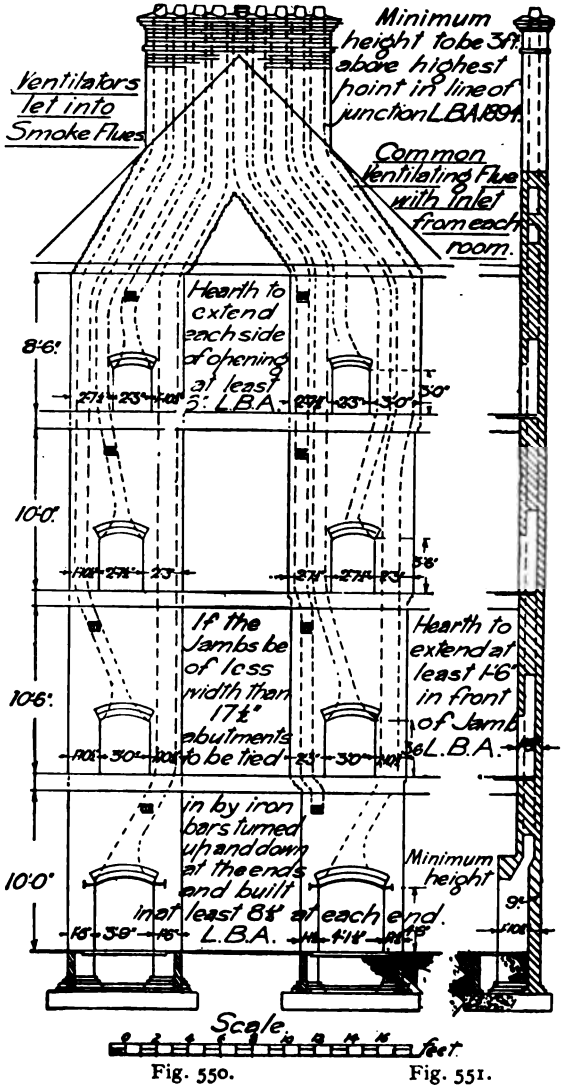


Fig. 550. Fig. 551.

Figure 546 shows the first method, with 9 in. × 9 in. flues, with the backs made 4½ inches in thickness, when, to comply with the Model Bye-Laws, they must be rendered. This arrangement is most usually adopted to curtail expense.

Figures 550 and 551, the usual arrangement of fireplaces and flues in the external walls of houses.

Figures 552 and 553 show an elevation and section of a system of flues back to back in a party wall. Figures 554 to 558 show the plan of the courses at each storey of this system.

The interlacing system, as shown in Figure 548, is sometimes used in order that the projection into the room may be as small as possible; but it could not be adopted in party walls, except where both houses belong to the same property, as the flues would project beyond the centre line. The diagonal method, as shown in Figure 549, is more particularly suitable for use in small rooms, where a fireplace near the centre of room would not be convenient. Angle fireplaces may be arranged with one or in groups of two, three or four at any one level.

Generally.—Every fireplace should have a separate flue, and in a stack the partition walls or withs must be smoke-proof. Any connection between flues causes smoky chimneys.

A grouping of flues in a building tends to economy and effectiveness.

The outer brickwork surrounding flues, to act effectively as a screen from the outer air, and as an efficient non-conductor of heat, is best where not less than 9 inches in thickness. The withs are usually half a brick thick, but great care must be exercised to have a thorough bond at the gathering over of the withs.

Chimney Bond.—The bonding in chimneys with 4½-inch backs is most effectively accomplished by the use of

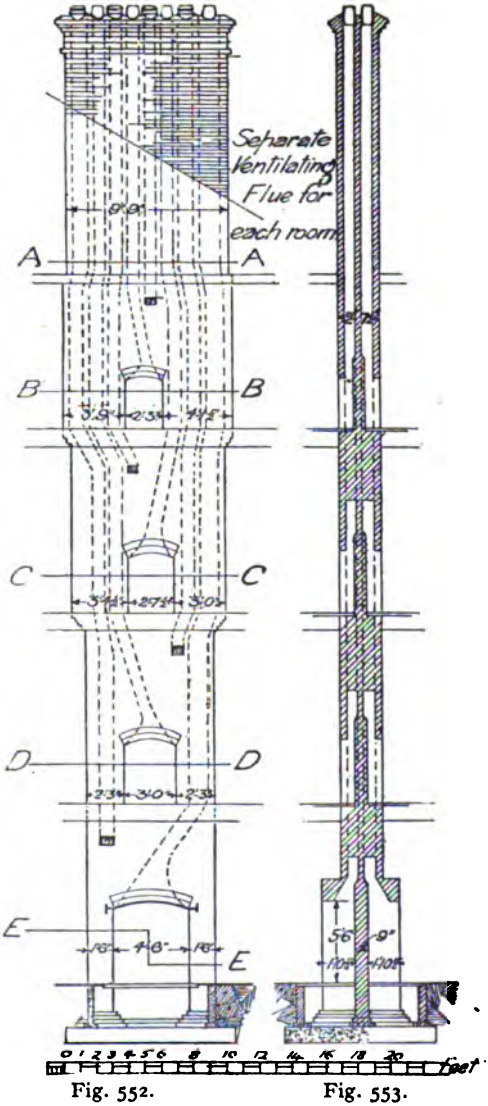


Fig. 552. Fig. 553.

Flemish bond; this method lends itself to the bricks of the withs of one course forming the face headers, and bats only being used on face in the alternate courses. The use of English bond for 4½ inch backs necessitates a considerable amount of cutting, thus causing the work to be weak and expensive.

Material for Flues.—The materials used for chimneys must be incombustible, durable, and sufficiently stable to resist external forces, such as wind pressure. Without the assistance of ties or any other special construction, brickwork best satisfies these conditions.

The following notes are based upon the requirements of the Model Bye-Laws, which are valuable as representing the product of considerable thought and vast experience:—

Dimensions of Flues.—Flues might very well be made 9 inches square; but the use of 14 in. × 9 in., or circular 12 inches diameter is enforced by section 6 of the "Act for the Regulation of Chimney Sweepers and Chimneys," 1840. There is but little doubt, however, that the use of a flue 9 inches square would very often prevent smoky chimneys, as on account of the smaller sectional area, a greater draught is created. Of late years 9 in. × 9 in. flues have been generally used as the standard dimensions for flues for ordinary purposes; 9 in. × 9 in. rectangular and 10 in. circular fireclay flues are largely used instead of the pargetted lining. These make a clean lining and the liability of the withs becoming imperfect is very much reduced.

Foundations for Chimneys.—The Model Bye-Laws provide that all chimneys must be built upon solid foundations with footings similar to those of the wall in which the chimney is built, or upon sufficient corbels of bricks or stone, or other incombustible substances, as in the case of a chimney commencing above a shop. This corbelling must not project more than the thickness of the wall below the corbel. The

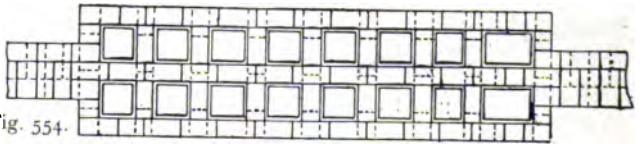


Fig. 554.

Section A.A.

Fig. 555.

Section B.B

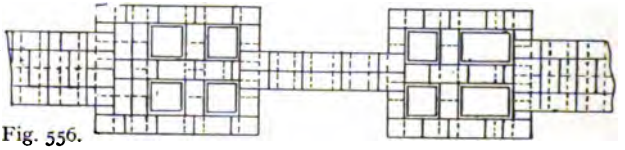


Fig. 556.

Section C.C

Fig. 557.

Section D.D.

Dotted lines show the alternate course

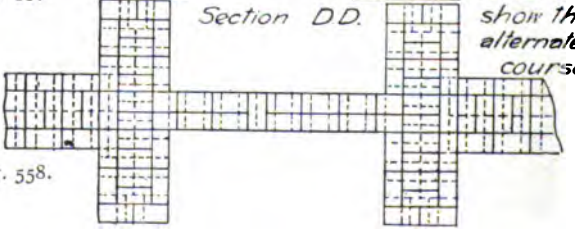


Fig. 558.

Section E.E.

Inches 2 1 0 1 2 Scale. 4 5 6 7 feet

corbelling must be done properly, otherwise the centre of gravity of the mass will be brought dangerously near the face of the lower part of the wall, and there will be a tendency to overturn, and the fall of walls inwards at times suggests this as one reason among others for the direction of the fall.

Pargetting.—All flues must be pargetted as they are carried up, unless lined with a fireclay lining 1 inch thick, or the spandrel angles filled in with brickwork, or other incombustible material. The back or outside of all flues must be rendered, if it be less than 9 inches thick, unless it forms part of the outer face of an external wall. Pargetting is a rendering on the inside of the flue with ordinary lime mortar. This is to provide against the accumulation of soot in the joints, or of fire penetrating them. The outside of flue breasts should always be rendered, especially behind skirtings and beneath floors, where it is more necessary than elsewhere, owing to the close proximity of woodwork.

Thickness of Backs of Chimneys.—Every flue of a furnace, steam boiler, or close fire used for trade purposes, or of any cooking apparatus or range of a hotel, tavern, or eating-house, must be surrounded with brickwork not less than 9 inches thick for 10 feet above the floor level. The back of a chimney opening in a party wall used for a kitchen range must be 9 inches thick for 6 feet above the chimney opening, and such thickness must be continued at the back of the flue; the backs of all other chimneys from the hearth up to a height of 12 inches above the opening must be at least 4½ inches thick if in an external wall, and 9 inches thick elsewhere than in an external wall.

Support of Chimney Breasts above Opening.—A sufficient arch of brick or stone, or a bar of iron, must be built over the opening of every chimney, and, if the breast project more than 4½ inches and the jambs be less than 13½ inches, the abutments must be tied in with a wrought-iron chimney

bar, 18 inches longer than the opening. In most cases the breasts project 9 inches or more, and, therefore, if the jambs are less than 13½ inches, these chimney bars must be used, one for each brick in the horizontal thickness of the arch. The ends of chimney-bars should be caulked, *i.e.*, cut and turned up and down.

Width of Jambs.—The Model Bye-Laws require that the jambs must be at least 9 inches wide on each side of chimney opening, and the brickwork surrounding any flue not less than 4½ inches thick.

Thickness of Brickwork on Upper Side of Flues.—Where flues make an angle less than 45 degrees with the horizon, the brickwork of the upper side must be at least 9 inches thick. This is a necessary provision to secure safety from fire, as if the upper side were not very substantial, the ascending heat might be a considerable source of danger.

Least Height of Chimney Stack above Roofs.—All chimneys must be carried up 4½ inches least thickness to a height of not less than 3 feet above the highest point in the line of junction with the adjoining roof, flat, or gutter. It is, however, generally advisable to carry the chimney 3 feet above the ridge-line to prevent down draught.

Maximum Height of Chimneys.—The Model Bye-Laws fix the following as the height to which chimneys may be carried above the roofs in exposed situations, although it may be necessary to make them of somewhat less height:—They shall not be built higher above the adjoining roof, flat, or gutter, than six times the least width of the shaft at the highest point of junction, unless built with and bonded to another chimney shaft not in the same line with it, or otherwise made secure. This does not apply to factory chimneys, for which a special construction is necessary.

Fastenings in Walls of Flues.—No iron holdfast or metal fastenings may be driven nearer the inside of a flue than 2 inches.

Proximity of Woodwork to Flues.—The provisions as to the proximity of woodwork to flues are briefly as follows :—

No woodwork must be built into walls or chimney breasts nearer than 12 inches from the inside of any flue, or under any chimney opening within 15 inches from the upper surface of the hearth. This relates to the insertion of timber beneath the back-hearth or chimney opening, and not, as might be supposed, to the lathing and bearers of the ceiling beneath the front hearth.

No wooden plug may be driven into any wall or chimney breast nearer than 6 inches to the inside of any flue or chimney opening.

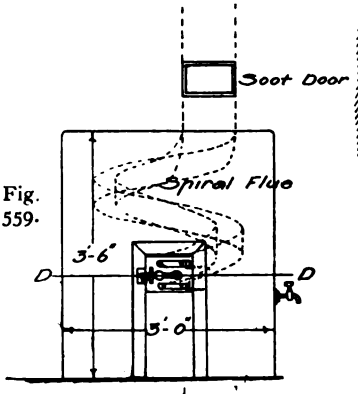
No woodwork must be nearer the face of the brickwork or stonework about any flue or chimney opening than 2 inches if the brickwork be less than 9 inches thick, unless the brickwork be properly rendered as before described.

Openings into Flues.—Openings for ventilating valves into smoke flues must not be less than 9 inches from woodwork, and in practice such openings are usually placed about 12 inches below the ceiling-line.

Soot Doors.—If any interior angle in a flue be less than 130 degrees a soot door must be provided for cleaning. This is usually specified as 6 inches soot door and frame.

Copper.—Figures 559 to 564 show the construction of an ordinary domestic copper. In these arrangements large quantities of water are required to be heated with rapidity for the purposes of cleansing linen and for other domestic purposes. It is necessary that the copper pan should have a large heating surface. A furnace is constructed beneath the pan and with a spiral flue about it. Section C-C shows the outline of the lowest course, section D-D shows the section through the furnace, Figures 560 and 561 show vertical sections through the copper and Figures 559 and 562 give the plan and elevation. The brickwork is externally rendered in cement to form a finish. A draw-off

Fig. 559.



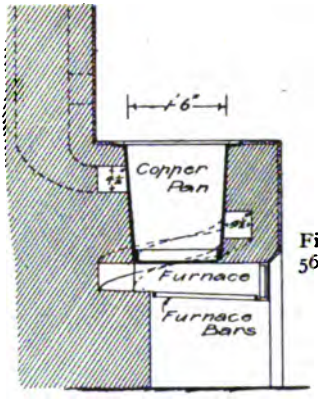
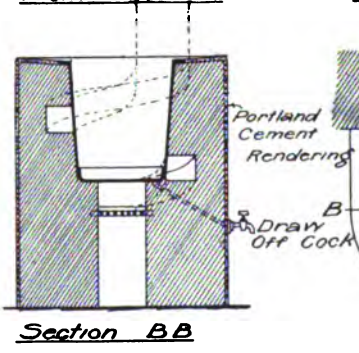


Fig. 560.

Fig. 561.



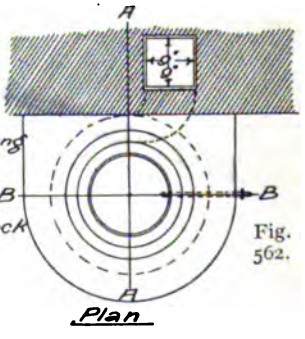
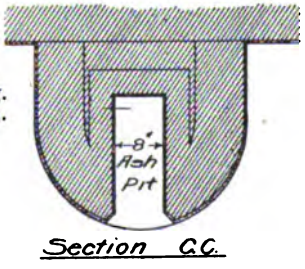


Fig. 562.

Fig. 563.



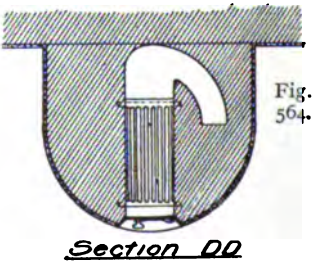
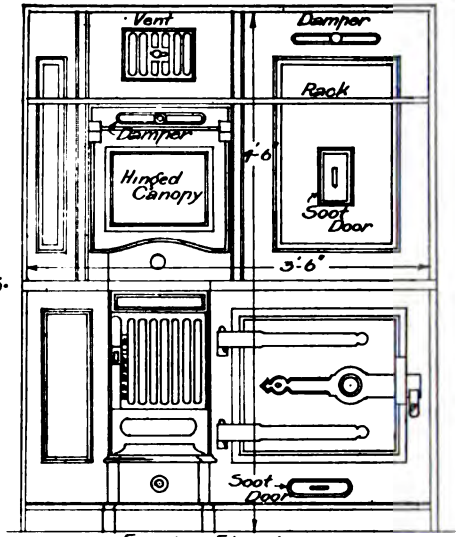


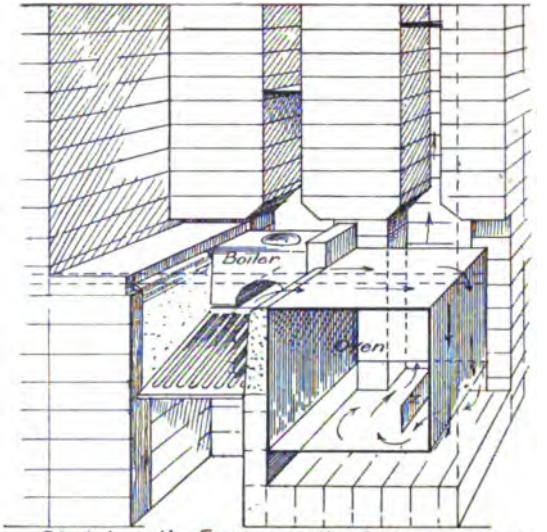
Fig. 564.

Scale 1/16 1/8 1/4 1/2 1 2 3 4 of Feet

Fig. 565.



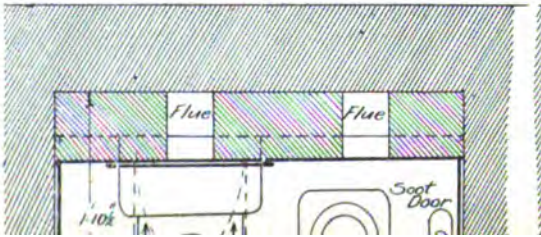
Front Elevation



Sketch with Front and Hot Plate removed

Fig. 566.

g. 567.



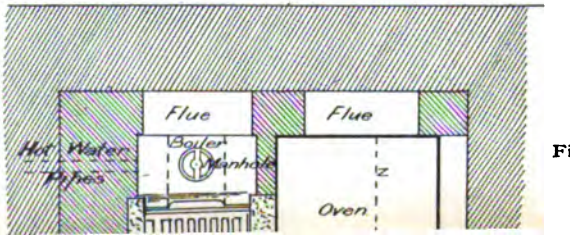


Fig. 568.

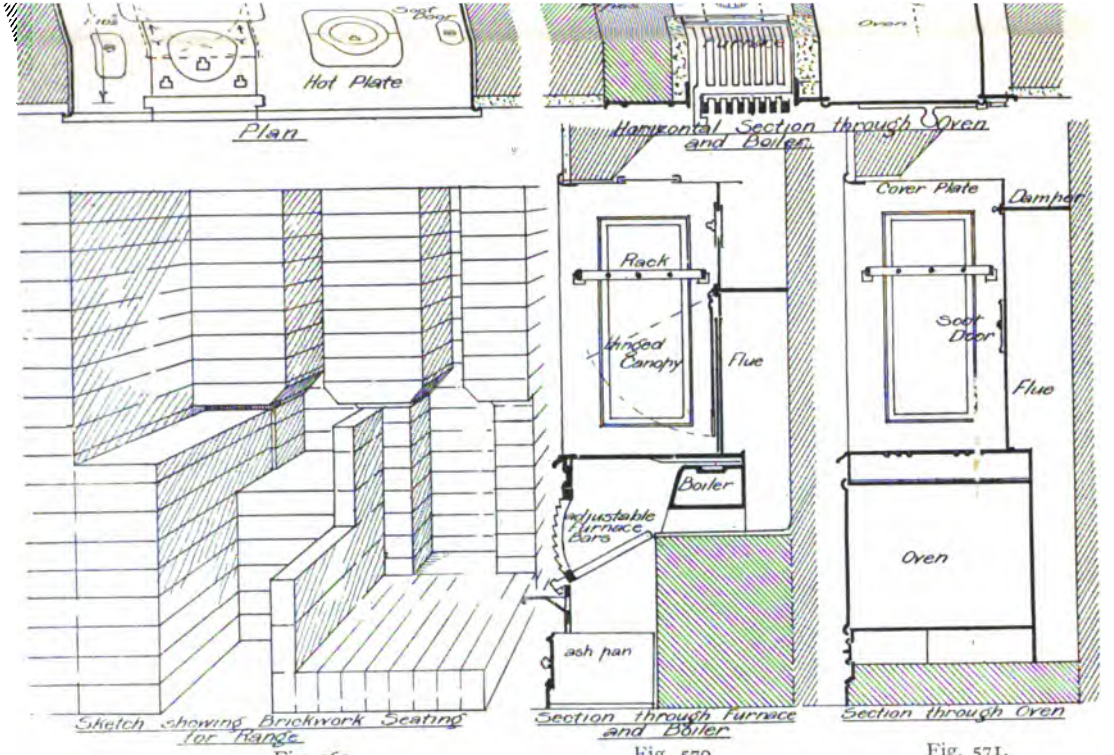


Fig. 569. Fig. 570. Fig. 571.

Figs. 565—571.

[*Between pages* 266 *and* 267.

cock is shown to remove all water from copper pan when the latter is not in use. These draw-off cocks are frequently omitted, but there is then great difficulty in removing water from the copper pan, especially when the latter is hot, should a change of water be necessary. A soot door should be provided in the lowest part of the straight flue to facilitate the sweeping of the flue.

Range.—Figures 565 to 571 show the arrangements of the parts of a kitchen range of modern construction, and the setting. An oven and arched high pressure boiler is shown. Economy of fuel is provided for by having a small furnace and causing the heat from the latter to traverse as large a surface of the oven and boiler as possible before finally being conducted up the flue. In this arrangement there are two primary flues, one each for the boiler and the oven. Should the oven be required to be heated rapidly, the boiler damper is closed and the oven damper opened; the heat then passes in the direction indicated by arrows, over the top of the oven, down the side, and is caused to pass towards the front of the oven by a thin iron partition marked L in the Figure, and finally up the flue at the back of the oven. Thus four sides of the oven are directly exposed to the heat. The side adjacent to the fire is protected by a fire-brick. The heat in passing over the top of the oven renders the whole of the hot-plate available for cooking purposes. Should it be required to heat the boiler rapidly the damper is withdrawn, the heat then being induced to pass under and up the back of the boiler.

The boiler is frequently placed at the side of the furnace similarly to the oven, the arrangements for heating the boiler being then identical with that of the oven. The oven and boiler flues discharge into a common flue above the cover plate.

If an open fire is required, the portion of the hot plate marked Y-Y directly above the furnace is pushed back in

the direction indicated by the arrows beneath the portion of the hot plate in its rear. The flap marked "hinged canopy" is then raised, and two side wings withdrawn, the heat then passes directly up the boiler flue. The furnace bars revolve upon a pivot at their back edge so that their bottom may be raised or lowered to adjust the quantity required at any time, the bottom is kept in any desired position by a rack and pawl arrangement as shown in Figure 570. For the efficient working of these ranges it is essential that the flues be kept thoroughly clean; for this purpose soot doors are arranged at every change of direction in the flues about oven and boiler. Figures 565 and 566 show plan and elevation of range complete; Figure 567 shows the arrangement of the brickwork for seating the boiler and oven; Figure 568 shows a similar sketch with the range front and hot plate removed, and showing oven, boiler and furnace bars in position; Figure 569 shows horizontal section through furnace, oven and boiler; and Figures 570 and 571 show vertical sections, one through oven, the other through furnace and boiler.

Register Grates.—For heating living rooms open grates are usually provided; these should be of the form known as slow combustion register grates. There are many varieties of these, subject to various patents, but the ordinary form is shown in Figures 572 to 576.

It consists of a cast iron frame and furnace bars, the back of the fire-basket being formed of purposely-made fire-bricks.

The requirements of these stoves are to obtain the maximum of heat with the minimum consumption of fuel and the most perfect combustion. In lighting, a rapid draught is required for a short time till the coal has ignited. To arrange for this a movable damper about the bottom of the fire-basket is provided, which when removed allows large quantities of air to pass through the fuel. When the coal has ignited the damper is placed in position,

Fig. 572. Fig. 573.

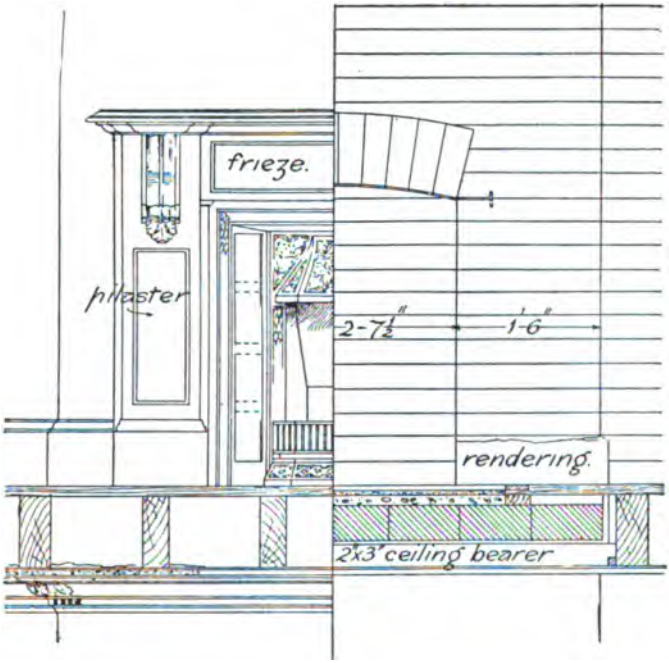
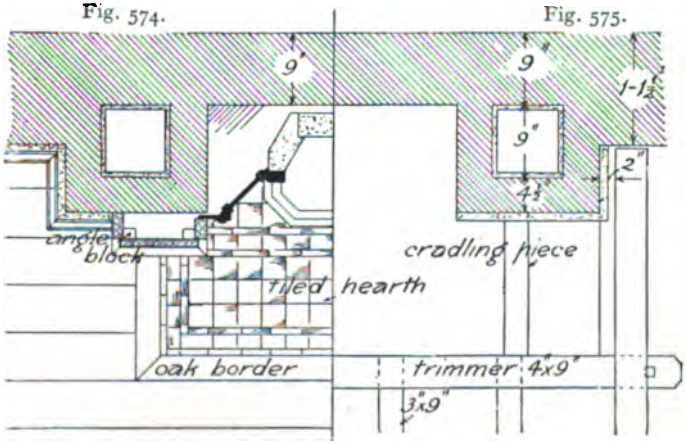
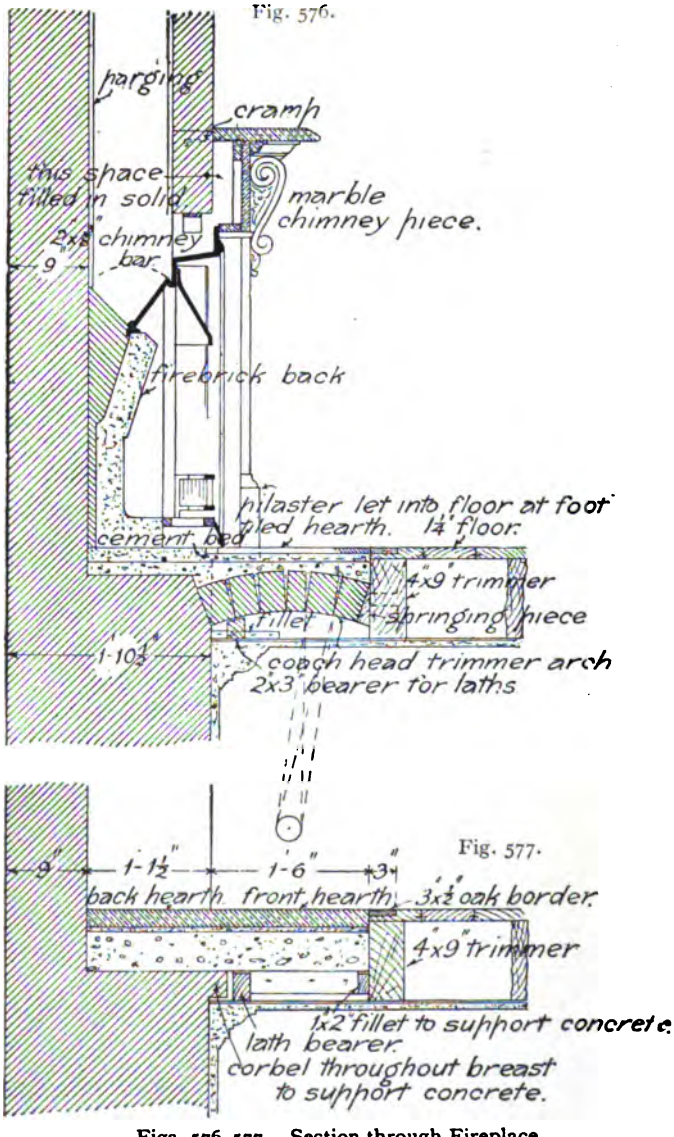


Fig. 574. Fig. 575.



Figs. 572–575. Example of Fireplace Construction.



Figs. 576-577. Section through Fireplace.

the supply of air is thus regulated and combustion takes place at a lower rate. The fire-brick back, to be efficient, must be at least three inches in thickness; this rapidly becomes red hot and thereby greatly assists in the more perfect combustion of the fuel. The fire-brick back is canopied over at the top in order to reflect the heat into the room while allowing the smoke to escape up the flue. The basket should be arranged as low as possible, not more than 2 inches above the hearth, so that the lower stratum of air in the room should be warmed. Figure 576 shows the metal canopy, behind which is an iron flap known as the register, which is closed as shown when the grate is not in use, to prevent soot falling from the chimney into the room. In many cases the register is omitted and the canopy is hinged.

In setting these grates they should be placed in position and built up solid about their sides; the upper portion of the back setting sloping downward as shown towards the register. The filling up between the top of the grate and the arch is omitted on the drawing to show chimney bar. Any neglect to completely fill up the sides and top of grate will result in a smoky fireplace. Figures 572 to 576 show an ordinary marble mantelpiece in front of grate, also the construction of trimmer arch and hearth; and Figure 577 shows the method of constructing hearth of concrete instead of using trimmer arch.

Proximity of Smoke Pipes to Woodwork.—No pipe used for conveying smoke or the products of combustion may be fixed at a distance less than 9 inches from any woodwork.

TALL CHIMNEY CONSTRUCTION.

In determining the dimensions of chimneys, the height is regulated by the draught required, and often to satisfy

sanitary conditions, while the dimensions of the diameter is a question of wind pressure.

The following notes may be found useful, when determining such problems relating to wind pressure.

Molesworth gives the following practical rules for chimneys:—

Let a = Area of fire-grate in square feet.
,, F = Quantity of coal consumed per hour in lbs.
,, h = Height of chimney in feet.
,, HP = Horse-power of engine (indicated).
,, A = Area of top of chimney in square inches.

$$\text{Then } A = \frac{15\,F}{\sqrt{h}} = \frac{100\,HP.}{\sqrt{h}} = \frac{180a}{\sqrt{h}}$$

and the velocity of the draught may be determined by the formula—

1296 Ht nearly = velocity of draught in feet per hour,
when H = vertical height of chimney in feet above fire-grate,
and t = difference of heated air column over external air in degrees Fahrenheit.

The regulations of the London County Council require the following points to be observed:—

If square, the width must be one-tenth of the total height. If circular, the width must be one-twelfth of the total height. The batter is to be $2\frac{1}{2}$ inches in every 10 feet, or an inclination of 1 in 48.

The brickwork must be at least $8\frac{1}{2}$ inches at the top and for 20 feet below, and the thickness of the brickwork must be increased $4\frac{1}{2}$ inches for every additional 20 feet of height measured downwards.

The fire-brick lining is to be additional to the thickness of the ordinary brickwork.

No cornice or other projection must stand out more than the thickness of the brickwork at the top.

Example.—Figures 578 to 583 illustrate a tall chimney complying with these regulations. Figure 578 shows half section and half elevation with the inlet flue and manhole for cleaning purposes, also the fire-brick lining and lining cover: this lining must be quite separate from the outer casing with a clear space of at least 2 inches. In many cases bricks are projected from the lining into this clear space to nearly touch the outer casing; these prevent any deformation of the inner lining by guiding the expansion upwards. Foot-irons are shown in the half section to admit of inspection and repairs. Figure 579 shows plan through flue and manhole. Figure 580 shows vertical section through flue. Figures 581 and 582 show plan through base and centre of shaft, and Figure 583 shows enlarged detail of a cast-iron cap and cornice surmounting the whole. The dimension of flue at exit should not exceed the area of the exit of fire-brick lining. Tall chimneys are usually built in hydraulic lime mortar, there being more elasticity in this than in cement mortar.

Caps are often of stone, but of late a great many have been made of cast iron, which is more economical and reliable than stone; the latter after fixing being subject to developing defects which, unless great skill and judgment are used, are liable to be overlooked.

Cramps, when made of iron and used in stone caps, oxidise and corrode, and often prove ineffective, and hence should be of gun-metal.

In circular chimney shafts, where stone caps are used, continuous gun-metal rings are sometimes employed instead of cramps to bind the courses of stonework together.

The limiting position of the centre of pressure of the forces acting upon square and circular chimneys has already been dealt with.

The principal disturbing force acting on chimneys is wind pressure, and to this force most attention must be

Fig. 583.

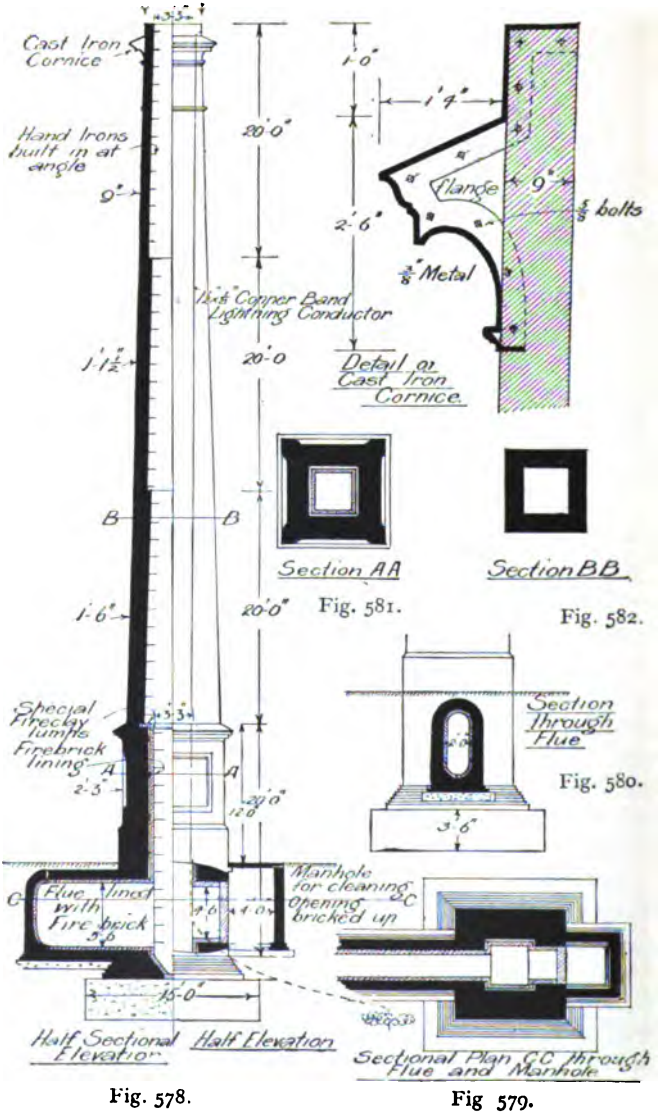


Fig. 581. Fig. 582. Fig. 580.

Fig. 578. Fig 579.

directed, 50 to 55 lbs. per square foot being the value usually allotted for wind pressuse resisted by the shaft.

In square chimneys, the total wind pressure is equal to the wind pressure (P) into the height multiplied by the width.

In circular chimneys the total pressure against the diametral plane is the height multiplied by the width by ·7854 P, due to the wind acting as a fluid pressing normally to the exposed surface, and thereby reducing the value of its pressure to ·7854, the value of the pressure against a wall at right angles to the direction of the wind.

The fire-brick lining must not be bonded in with the brickwork of the shaft, but quite free, so that it can expand and contract independently of the ordinary brickwork.

Lightning Conductors.—Chimney shafts and the highest parts of structures elevated above surrounding objects should be protected from the effects of lightning by attaching a metal band of good conductivity to form an electrical connection between the earth and the clouds. All metals are good conductors compared to the other materials of a structure, and will collect and convey currents which, if not properly guided away from the building, are likely to form a source of danger to the structure. All metal parts, such as gutters, should be connected with the conductor. The lightning conductor is usually a band or rod of copper or iron commencing at the highest part of the structure, where it is connected to a terminal extending from 4 to 6 feet above the highest part. The end of the terminal is pointed, and has a number of pointed branches extending out from the central stem. The conductor is fixed to the wall, often close to it, and is continued down to the ground. Here it is diverted horizontally so far away from the structure as is necessary to find good moist earth, and attached to a metal plate, usually copper, about $\frac{1}{8}$ inch in thickness and at least 3 feet square, the actual area depending upon the nature of the earth, which

should be wet; the drier the ground, the larger, therefore, will be the required area. In order to obtain an efficient contact, the earth plate is surrounded by powdered coke about 6 feet below the surface of the ground. Copper is a better conductor than iron in the ratio of 100 to 17, and the relative areas to convey a similar current would therefore be in the inverse ratio. Copper is easier to manipulate about the various architectural projections, but iron is better to resist fusion. Care should be taken that all joints are efficiently made, so that the pieces joined are in actual contact; copper should be rivetted and soldered, and the iron screwed or rivetted according to section.

The zone protected by a conductor is generally considered to be that space enclosed by a cone the base of which is twice its height, hence the necessity in long exposed buildings to have conductors at all salient points. Figure 578 shows the shaft protected by a lightning conductor attached, taken down to the ground and properly earthed.

CHAPTER X*.

GAUGED WORK.

Definition.—All brickwork in which the bricks are cut to definite sizes and shapes is known as gauged work.

Classification.—There are two kinds of gauged work, axed and cut and rubbed work.

Tools required.—These are described at the end of the chapter on brickwork.

Axed Work.—This labour is usually placed on the voussoirs of arches constructed of bricks too hard to be economically cut with the saw. It consists of reducing the brick to the required form by means of a bricklayers' axe or a scutch, the process being as follows:—A templet is prepared of wood about $\frac{3}{8}$ of an inch thick of the shape required. The templet is laid upon the brick which is marked and cut with a tin saw, the cut being sunk about an $\frac{1}{8}$ of an inch in depth; the ends are squared over and cut, and the back of the brick treated in a similar manner. The required shape being now outlined, the superfluous portions of the brick are removed with a bolster and hammer, the brick is now placed on the chopping block as shown on page 94 and the cut surface levelled with a scutch. The object of sinking with a tin saw is to preserve a sharp arris about the brick. Mouldings cannot be economically cut on hard bricks, therefore, these bricks are usually moulded before burning

Cut and Rubbed Work.—In highly finished brickwork special bricks are employed known as cutters or rubbers (see chapter on bricks) that can be easily cut and worked to the required forms. The bricks are cut with a bow saw, which latter is shown in page 94, and the surfaces of the brick are finished by rubbing them with a stone or with a file. The processes vary slightly with the particular work in hand, but four general operations include most of the work in general practice, viz.:—1, squaring up as in ashlar work; 2, straight moulded work; 3, circular work, plain or moulded; and 4, work of double curvature. The object of rubbing gauged work is to produce regularity and extreme fineness in the joints, these being made from $\frac{1}{32}$ to $\frac{1}{16}$ of an inch in thickness. To produce such joints the substance of the bedding material must be reduced to a very fine state of division. Pure slaked lime known as putty is the material employed.

Preparation of Putty.—Chalk lime is slaked with an excess of water, and the water, with the particles of lime in suspension, is passed through a very fine mesh sieve into a box known as the putty box—all particles that are too large to readily pass through the sieve are rejected. This mixture of lime and water is allowed to stand until the particles of lime have been precipitated. The excess of water is then poured off, and the resulting compound is allowed to stand for at least a week before using to ensure thorough slaking. Immediately before being required for use it is well worked up with a trowel to give it the necessary plasticity.

Bedding Rubbed Work.—In bedding rubbed work the bricks are well wetted and the putty is spread in a thin layer of about $\frac{3}{4}$ of an inch in width about every seen edge. The bricks are then rubbed together with considerable pressure to squeeze out the excess of putty, the back of the work should then be well grouted with neat portland

cement. For arches, grooves or sinkings are formed in the side joints, as shown in Figure 589, in order that the portland cement grout may fill up the sinkings and form cement joggles.

Wood Cutting Moulds.—These moulds or boxes are made of pine from $\frac{1}{2}$ to 1 inch in thickness according to the requirements, they consist of a base board into which is housed two profiles of the work required, these profiles are stiffened by angle brackets as shown in Figure 584. The bricks to be cut are placed between the profiles and wedged in position to prevent any movement, and the wire saw is passed through the brick and worked over the edges of the profiles, thus giving to the brick the desired form. To prevent the profiles rapidly wearing by the friction of the saw, the edges of the profiles rubbed are protected with strips of zinc or tinned sheet iron tacked to them.

Plain Work.—The flat or camber arch, Figures 584 to 587, illustrates an example of plain work. This is the simplest labour, and is usually employed for what is known as ashlar work, i.e., plain walling, with fine and regular joints on an even true surface. The 9 inch by $4\frac{1}{2}$ inch surface is rubbed with a circular motion on the rubbing stone. When the whole face is reduced it is tested for accuracy upon the surfacing slate, the latter is shown in Figure 589; the 9 inch by 3 inch surface is then rubbed and tested with a square, one end is now rubbed and squared with the two previously prepared faces, the brick is then placed in a thicknessing mould, as shown in Figure 588, and is cut to a length and thickness with the wire saw, these sawn surfaces being finished with a hand stone or file. If the brick requires to be taken to a width it is placed in a cutting mould to the width and reduced by a wire saw as before.

The Flat or Camber Arch.—This arch requires to be accurately drawn on paper. The depth of the arch is invariably made some multiple of the thickness of a brick.

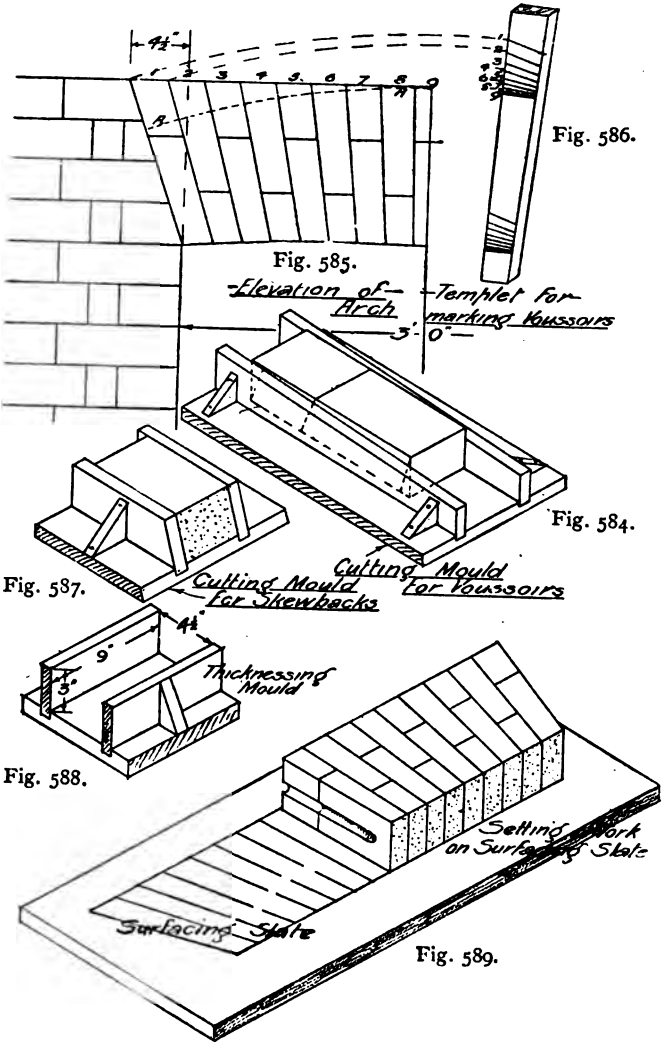


Fig. 585.

Fig. 586.

Fig. 584.

Fig. 587.

Fig. 588.

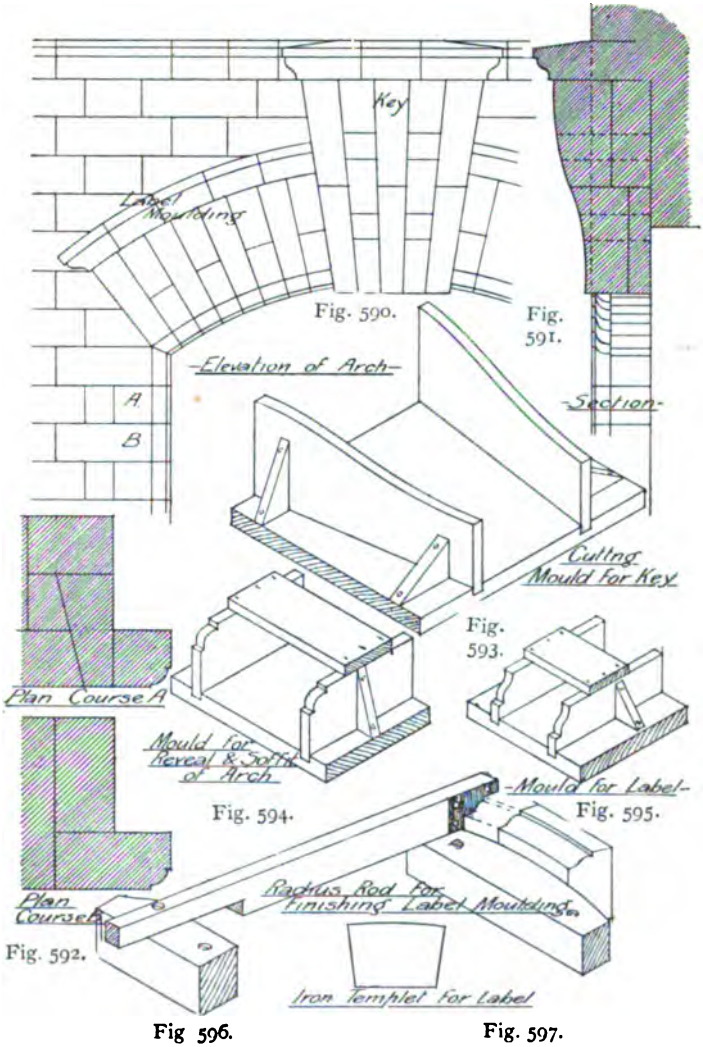
Fig. 589.

The extrados is worked perfectly horizontal; the intrados is given a camber, that is, an upward curve to allow for any slight settlement and to correct the apparent sagging of a horizontal line, the usual allowance being $\frac{1}{8}$ of an inch rise in the centre for every foot of span. The amount of skew-back should vary with the span of the arch, $1\frac{1}{2}$ inches for every foot of span in a depth of 12 inches gives good results. The centre of the arch will be at the intersection of the skewback lines produced; the voussoirs should be divided upon a segment drawn from the centre and tangent to the extrados as shown at A A, Figure 585; an odd number of bricks is required to give a key brick. The lowest bricks in key and springers should be stretchers; to obtain this the number of voussoirs must be odd, and some multiple of four plus one, as, 5, 9, 13, &c. The heading joints should be all kept horizontal. A templet, as shown in Figure 586, of $\frac{3}{4}$ of an inch pine is prepared, and on this the correct form of every voussoir is marked as shown in Figure 586. The bricks are then prepared by rubbing one face and squaring one edge, they are arranged in pairs with the exception of the key. The heading joints are next formed, the bevils being taken from the templet, then marked on the bricks, cut with the saw and the joints finished accurately with the stone. The extrados and intrados of each voussoir is cut and finished in a similar manner; the templet is then applied to the face of the voussoir, the tapering is marked on and the voussoir placed in the cutting mould, as shown in Figure 584, adjusted and wedged in position, the superfluous portions of the brick are removed with a saw and the surface finished with a flat file. The voussoirs are jointed together on the surfacing slate, either into the complete arch or into convenient sections, the back of the joints being grouted with portland cement. In setting the arch it can be placed *en bloc* on the turning piece and between the skew-backs prepared to receive it, or if large

the various sections are jointed together on the turning piece. The arch may be built upon the turning piece, in which case the exact position of each brick must be marked thereon.

Skewbacks.—If the dressings and skewbacks are out of rubbing bricks, the skewbacks should be shaped in a cutting mould, as shown in Figure 587, to the correct bevil. If the skewbacks are of hard facing bricks, they are incised with a tin saw, cut with a bolster and scutch, and the arrises finished with a hand stone. In setting the skewbacks, they are tested for accuracy with a templet when in position.

Circular Work.—This work is illustrated in Figures 590 to 597 by a segmental arch with key and label moulding. As in the preceding example, a full-sized drawing must be made of a little more than half of the arch, a templet of pine $\frac{3}{8}$ of an inch thick is prepared of sufficient length to mark the key voussoirs. The arch and reveal bricks are then faced and squared, the reveal bricks are thicknessed; they are then placed in the cutting mould, shown in Figure 594, for working the angle moulding. This may be made sufficiently large to cut two or three bricks at a time. The arch bricks are then placed in a wedged-shaped cutting mould, and reduced by the wire saw to the correct form; the key bricks are squared and cut to the shape of the voussoir, the whole being jointed and set to form the complete key block. These are then placed in a special shaped cutting mould, shown in Figure 593, to cut them to the face curve. The bricks for the label moulding are bedded on their large faces; they are sufficiently wide to necessitate cutting to the circular form. After squaring and receiving their wedge-shaped form, they are placed in a cutting mould, shaped to give the proper curve to the lower bed. The moulding is circular and cannot be worked in one operation, but the


Key
Label Moulding
Fig. 590.
Fig. 591.
Elevation of Arch
Section
A
B
Cutting Mould For Key
Fig. 593.
Plan Course A
Mould for Reveal & Soffit of Arch
Fig. 594.
Mould for Label
Fig. 595.
Plan Course B
Radius Rod For Finishing Label Moulding
Fig. 592.
Iron Templet For Label
Fig 596.
Fig. 597.

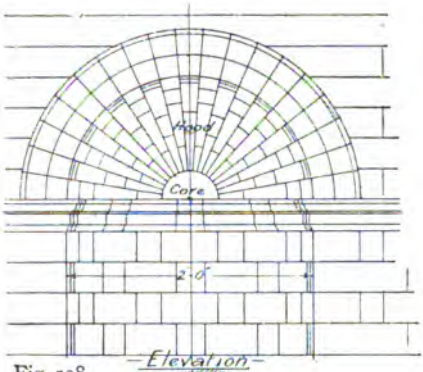
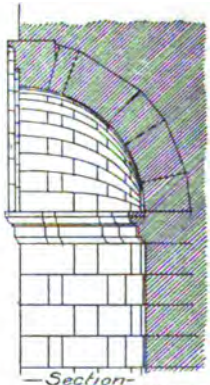


Fig. 598. —Elevation—



—Section—

Fig. 599.

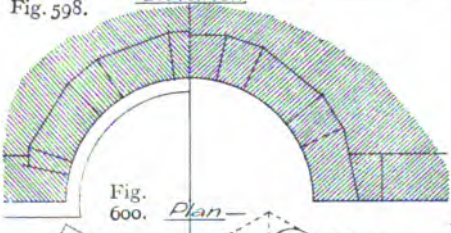
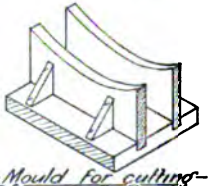


Fig. 600. —Plan—



—Mould for cutting—
—faces of bricks—

Fig. 601.

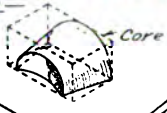


Fig. 603.

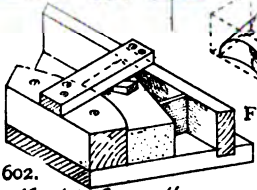
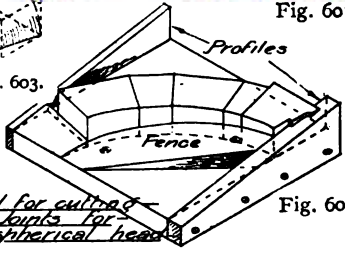
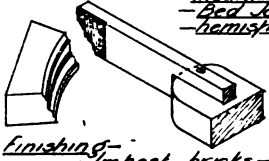


Fig. 602.
—Mould for cutting—
—side Joints—



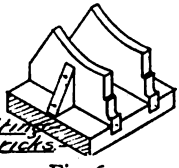
—Mould for cutting—
—Bed Joints for
—hemispherical head

Fig. 604.



—Finishing—
—Impost bricks—

Fig. 606.



—Mould for cutting
—Archivolt bricks

Fig. 605.

bricks are placed in a cutting mould, shown in Figure 595, of the correct profile; the moulding is cut straight from side joint to side joint, then the moulding is worked to the finished form with a radius rod, to which is fixed a steel cutter, as shown in Figure 596. If the curve is very quick it is eased with a file, the cutter only being finally used. The extradosial curve on the label moulding is marked with a templet, Figure 597, and the surplus material removed with a file.

Circular, Circular Work.—This labour, which consists of the preparation of surfaces, circular in plan and circular in elevation, is illustrated by the niche shown in Figures 598 to 606. A full-size drawing must be made of the plan and elevation of the niche. The bonding of the body of the niche must be carefully set out, taking care to place a stretcher in the centre of the second course below the springing line. The bonding of the hood of the niche will follow that of the body.

The Body.—The bricks for the body of the niche are first trued up on one wide face, then reduced to a thickness in a thicknessing mould; afterwards they are placed in a mould, Figure 601, to cut their circular sunk faces; then they are placed in a mould, Figure 602, to cut the side joints, the circular sunk face being wedged against a circular face to ensure all the side joints being cut to the correct form.

The Impost.—The bricks for this feature are squared, thicknessed, and have their circular sunk form given to them by cutting in moulds similar to those used for the body of the niche. A zinc profile of the moulding is placed on each side joint of the bricks and marked, and the moulding is roughed out with files and finished with a radius rod and steel cutter, shown in Figure 606.

The Hood.—The bricks for the hood are squared on one of the 9 by 4½ inch faces, they are then circular sunk,

and the side joints are cut in the same moulds used for the bricks in the body of the niche. The moulded archivolt bricks are then prepared by first squaring one of the large faces, they are next placed in the mould shown in Figure 605, and the moulding and the circular sunk face are cut in one operation. The side joints are then cut in the mould used for the body of the bricks. The centre is then prepared by trueing up the large face of a brick, thicknessing and squaring an edge. The centre consists of a semi-truncated cone, the truncated cone being supposed halved by a plane containing its axis. With the compasses alternately set to the radii of the two bases of the semi-cone, draw semi-circles large and small on the back and front faces respectively, as shown in Figure 603. The surplus material is removed, and the conical surface finished with a file, and the front face worked hollow to the concave spherical surface with a file, and is finished by a rubbing stone when the whole hood is complete.

The bricks forming a voussoir of the hood are now jointed and placed on a cutting mould, as shown in Figure 604, the concave face being in contact with the fence; the saw is run down the plane containing the two edges of the profiles and the upper surface of the fence, removing the brickwork projecting above the plane, thus forming the required voussoir.

All the voussoirs are identical in form and are cut in a similar manner.

Building up of Niche.—The bricks in the body of the niche are first built, each course being tested for accuracy with a wood templet of the correct circular form. For the hood, a circular wood rib is required to support the front edge of the voussoirs, the correct position of each course being marked upon the wood rib and also upon the centre block or boss, to ensure each voussoir being bedded in its correct position. When the whole hood is complete it is

well grouted at the back with portland cement. The archivolt moulding is then finished with a radius rod and steel cutter.

The given examples illustrate the cardinal principles of the art of brick cutting; other cases, such as projecting pilasters, cornices, string courses and moulded panels, are easily dealt with if the bonding has been properly set out.

When designing brick cornices the lengths of the bricks should be borne in mind and the projection of the courses should never exceed one-third of a brick; this renders bricks an unsuitable medium for constructing modillion cornices. If such cornices are needed, the modillions should be constructed of stone similar in colour to the bricks and extending through a sufficient thickness of the wall, as shown in Figure 164, to ensure the safety of the crowning mouldings from overturning. The total mass of the projecting cornices must not be sufficiently great to endanger the stability of the wall.

Breaks in cornices, especially those that contain dentil cornices, present difficulties at the mitres or angles, the bricks not being sufficiently large to have a return moulding worked upon them and still leave a bed sufficient for stability. In all such cases these bricks should be secured by iron cramps caulked into their upper bed. The bulk of the angle brick is often increased by joining two bricks together with shellac in order that no putty joint may be visible. This latter expedient, though often necessary, is not to be recommended, but the design of the work should be modified to suit the material. Cornices of Gothic character, owing to their small projection, as shown in Figures 158 to 162, are much more suitable in cut brickwork than those having a classical "motif."

Joints in cut brickwork should be normal to the exposed surface, as in stonework there should be no exposed angles less than 90 degrees, and all mitres should be of the kind

known as Mason's mitres. Great care should be taken that the rubbing bricks should be kept perfectly dry before being worked, as they become extremely hard and difficult to work if once wetted, therefore these bricks should always be stacked under cover and the cutting operations take place in a closed shed.

Shellac is a resinous gum. It is dissolved in spirits of wine. For use it requires to be of about the consistency of cream. The shellac in solution is too thin for use. To reduce it to the proper consistency it is placed in water and stirred, which has the effect of dissolving the spirit which is in excess. The shellac is taken from the water and is ready for use. For joining bricks a close joint is made, a thin layer of the shellac is spread over the surface, and the two pieces are rubbed together to squeeze out all the shellac in excess.

CHAPTER XI.

LIMES AND CEMENTS.

Limestones.—Stones consisting entirely or in a great part of carbonate of lime, $CaCO_3$, are known as limestones, and are quarried chiefly in the form of chalk, which is a soft white rock of almost pure carbonate of lime, limestones, and marbles. For descriptions of the latter two, see Chapter on Stones.

The resultant of limestones after burning is lime, which is used in building operations (*a*) as a matrix for concrete, (*b*) in the preparation of mortar for bedding bricks or stones in walling, and (*c*) as a cementing material in the plaster used for the covering of walls.

Classification.—Limes are classified under the following heads:—

1. Pure or rich limes.
2. Poor limes.
3. Hydraulic { Feebly hydraulic. Hydraulic. Eminently hydraulic.

Limestones are never found absolutely pure in nature, but are either mixed with or in combination with impurities, which latter, if soluble in acids, are useful in accelerating the setting action, but if insoluble in acids are valueless for that purpose.

Rich Limes.—Limes are said to be rich or pure when the impurities insoluble in acids do not exceed 6 per cent. of the whole mass.

Rich, pure, or fat limes should only be used for plastering, because of their readiness to slake, and their consequent non liability to blister as compared to hydraulic limes.

Poor Limes are those containing from 15 to 30 per cent. of impurities insoluble in acids. They possess the general properties of rich limes, but in a lesser degree. They take longer to slake, and do not increase in bulk to such an extent as the rich limes. They will not take such a large ratio of sand, owing to the foreign matter they already contain.

Hydraulic Limes contain a quantity of combinable substances other than lime, such as silica and alumina, which on being burnt form a calcic aluminate and calcic silicate, together with a portion of pure lime, the measure of these bodies up to a certain point being the measure of the hydraulicity. These bodies render the lime independent of external agents for its setting properties.

Limes containing 6 to 16 per cent. of these useful substances are termed feebly hydraulic, those containing 16 to 26 per cent. hydraulic, and those with from 26 to 36 per cent. eminently hydraulic.

Hydraulic limes only should be used as the matrix for lime concrete, and they are most suitable for constructional work.

From the time limestone is quarried to the setting of the lime in the work, four processes are gone through, viz., burning, slaking, mixing with sand, and setting.

$CaCO_3$ is a substance insoluble in pure water, and is unable to combine with carbonic acid gas when in this form, but is rendered suitable by calcination, which drives off the carbon dioxide (CO_2), leaving calcium oxide (CaO), together with any other impurities contained in the stone.

Burning of Limestone.—Limestones are burnt in kilns of various shapes, the most common being a cylindrical brick or stone casing lined with fire-brick, having a draw-hole

at one part to apply the fuel; this is termed a flare kiln. A rough dome is built with the limestones, forming a chamber to contain the fire; the kiln is then filled about the dome, the top of the kiln being usually covered by a shed to protect it from the weather.

In burning the limestone, the heat should be applied gradually, otherwise the separation of the carbon dioxide from the stone takes place with such rapidity that the stones crumble to pieces.

It is imperative that the calcined stones should be withdrawn from the kiln as soon as the carbon dioxide has been driven off, this being determined as follows:—While any carbon dioxide remains in the stone it will be of a dark red colour, but when this has passed off it is changed to a brilliant white glow; at this point the stone should be withdrawn, or it will be overburnt, the result being a lime which is very difficult to slake, this action not taking place for a considerable time after the mortar has been made, rendering the lime unreliable for use, as it would commence to blow when bedded in the work. A somewhat similar result occurs with underburnt lime.

Slaking.—The object of slaking lime is to form a calcic hydrate, thus rendering it quickly in a fit condition to readily combine with the CO_2 to form crystals, the formation of the latter being a necessary condition for strength in a mortar. Slaking is induced by adding water to quicklime; these on combining give off great heat and form steam, which causes the lime to expand, burst, and disintegrate with a series of small explosions forming a calcic hydrate (CaH_2O_2), a whitish-yellow powder. The slaked lime thus formed is soluble, and hence when more water is added some of this dissolves and forms a saturated solution.

The soluble lime in a saturated solution is ready for the absorption of CO_2, which always exists in the atmosphere.

If quick-lime be left exposed to the air, it absorbs CO_2, which under these conditions renders it inert, as the resulting carbonate is not crystalline.

Slaking is an important process in the manufacture of mortar, and it is imperative that every particle of quick-lime must be thoroughly slaked, for if any unslaked portions are built in the work it will by its subsequent expansion disturb the rest of the work.

To obviate this failing, the mortar should always be kept for at least fourteen days after mixing before being used.

Sand is added to lime in the preparation of mortar, (1) to counteract the excessive shrinkage that takes place with pure lime mortar, (2) to assist in the crystallization by forming ducts through which the necessary CO_2 can have access and act upon the particles behind the surface, and (3) to increase the bulk of the mass (sand being much cheaper than lime).

The sand for mortar should be free from all earthy or clayey matter; it should have sharp angles and a rough surface.

The best sand for building purposes is that known as pit sand. The next in order is river sand, which is obtained from the banks and beds of rivers; this kind is not considered so good as pit sand, the grains being rounded and worn smooth, the adhesive value being thus reduced. River sand is, however, largely used for plasterers' work, it being fine and of a light colour. The grains in sea sand are similar to river sand, round and smooth. Sea sand should never be used for plastering nor other building work, as it effloresces, thereby causing a wall to be damp for a considerable time.

Sand should be fine for plasterers' work, and moderately coarse for bricklayers' work; it is usually screened and sometimes sifted to remove any large stones or shingle that it may contain.

Loamy or dirty sand should be washed before being used. This is usually effected by placing the sand in a vessel through which a stream of water is constantly passing, the sand at the same time being agitated to separate it from the foreign matter, which latter becomes suspended in the water and passes off.

Sand for all coats of plasterers' work is best washed, although for the first coats this is often neglected.

Setting of Lime.—The setting of lime depends on the absorption of CO_2 from the atmosphere by the particles of slaked lime in solution in the mortar, the carbon dioxide being soluble in water. The CaO and CO_2 combine to form crystals of $CaCO_3$, these being deposited, and giving up the H_2O, which combines with the next particle, forming it into a saturated solution, rendering it into the necessary condition to take up another molecule of CO_2; this in its turn crystallizes and is deposited: this process is repeated till the whole has set. The crystals always have a tendency to adhere to something rough and hard, such as sandy particles or the surfaces of bricks; for this reason the addition of sand up to a certain ratio increases the strength of the mixture, the best ratio being one part pure lime to one of sand, the maximum being one of pure lime to three parts of sand.

A long time elapses before pure limes harden, owing to their depending upon external aid to attain this state. If lime alone were used the surface would set and form an impervious layer, and so check the CO_2 from acting on those particles below the surface, the moisture in which evaporates and leaves it in the state of a powder; and even when a large proportion of sand is used and the mass made porous, the supply of CO_2 must necessarily be small, and a long time elapses before the material hardens. Pure lime mortar built in thick walls never hardens nor sets, but crumbles into a friable powder.

For this reason pure limes should be avoided for constructional work, and a lime or cement which does not depend on external aid to set, be used.

Setting of Hydraulic Limes and Cements.—The setting of hydraulic limes and cements is due chiefly to the formation of crystals of hydrated calcic silicate and hydrated calcic aluminate, and a typical Portland cement would be represented somewhat as follows :—

$$(CaO)_2 . Al_2O_3H_2O + 3 (2 CaO, SiO_2 H_2O)$$

and in hydraulic limes to a certain extent to the absorption of CO_2, there being in most of these a small percentage of free lime.

As these limes and cements do not depend on external agencies for their setting properties, they are able to set in the centre of thick walls and under water. This renders them valuable for all constructional work.

Hydraulic limes possess none of the marked characteristics of the pure limes in slaking: they do not increase very much in bulk, and the slaking takes a much longer time to accomplish.

Blue lias lime, from the rocks of the lias geological formation, is one of the best natural hydraulic limes. It is obtainable from Lyme Regis in Dorsetshire, Keynsham in Somersetshire, Shipston and Rugby in Warwickshire, Barrow-on-Soar in Leicestershire, Aberthaw in Glamorganshire, also in Flintshire, Lincolnshire, and Yorkshire.

Hydraulic Lime Mortar.—Slake the lime the day previous by sprinkling it lightly with water, then turn it up together in a heap, and cover it with sand. The next morning it may be made into mortar by adding the proper proportions of sand and water. One part of lime and two or two and a half parts of sand make excellent mortar.

Gypsum—Chemical Analysis.—Plaster of Paris is anhydrous calcic sulphate, $CaSO_4$, and is produced by the

gentle calcination of gypsum, which is a native hydrated sulphate of lime, occurring as a soft stone ($CaSO_4 . 2H_2O$) usually of a more or less crystalline texture, and varying in colour from white to shades of brown and grey to black. It is found in Derbyshire, Nottinghamshire, Cheshire, Westmoreland, and in great abundance near Paris. It contains in every 100 parts by weight, 46·5 parts of SO_3, 32·8 parts of CaO, 20·7 parts of H_2O. The raw stone is sometimes ground in the first instance and calcined in iron vessels. The very fine-grained pure white variety of gypsum is termed alabaster; the transparent, selenite.

Characteristics.—This is the only building material which at the time of setting expands in volume, which property makes it valuable for filling up holes and other defects.

Uses.—It is used for making ornaments for ceilings, etc., and where plentiful may be used in all parts of a building where it is not exposed to the weather, for which it is unfit, being very soluble in water.

Its effect when mixed with the ordinary limes is to arrest the slaking and to increase the rapidity of setting.

Selenitic Cement or Selenitic Lime is an invention of General Scott, and is made by adding to the limes of the lias formation, which are the best for the purpose, or to the magnesian limestones or any lime possessing hydraulic properties, a small proportion of sulphate of lime in the form of plaster of Paris, mechanically mixed and ground with lime.

Chemical Synthesis.—The proportion of sulphate the cement usually contains is from 4 to 7 per cent., usual proportion being 5. When more than 7½ per cent. of sulphate is required to suppress the slaking action, the lime is not suitable for selenitic cement, but may be rendered so by adding a lime that contains more clay.

Characteristics.—The sulphate suppresses the slaking

action of lime, causes it to set more quickly, and enables it to be used with a much larger proportion of sand than ordinary lime without loss of strength.

Uses.—For building mortar and plasterers' work.

Messrs. C. Nelson & Co., manufacturers of this material, issue the following instructions for the preparation of selenitic mortar for bricklayers' and plasterers' work:—

PATENT SELENITIC BLUE LIAS.

"One bushel of lime (selenitic) requires about six gallons of water (about two full-sized pails).

If Prepared in a Mortar Mill.—(1) Pour into the pan of the edge runner four full-sized pails of water.

(2) Gradually add to the water in the pan two bushels of selenitic lime and grind to the consistency of creamy paste.

(3) Throw into the pan ten bushels of clean sharp sand, burnt clay, or broken bricks, which must be ground till thoroughly incorporated (but over grinding in the case of burnt ballast or broken bricks is apt to cause cracking). If necessary, water can be added to this in grinding, which is preferable to adding an excess of water to the prepared lime before adding the sand. When a mortar mill cannot be used an ordinary plasterer's tub (containing about thirty or forty gallons) or trough with outlet or sluice may be substituted."

"*If Prepared in a Plasterer's Tub.*—(1) Pour into the tub four full-sized pails of water.

(2) Gradually add to the water in the tub two bushels of selenitic lime, which must be kept well stirred until thoroughly mixed with the water to the consistency of creamy paste.

(3) Form ten bushels of clean sharp sand into a ring and pour in the selenitic lime from the tub through a quarter-mesh sieve (to avoid clods) adding water as necessary. This

should be turned over two or three times, and well mixed with the larry or mortar hook.

Both the above mixtures are suitable for bricklayers' mortar or for first coat of plastering on brickwork.

Plastering on brick can be floated or straightened in one coat, and requires no hair."

"*For Plastering on Lathwork.*—To the above quantity of water and selenitic lime add only six or eight bushels of clean sharp sand and two hods of well-haired lime putty; the hair being previously well hooked into the lime putty. When the mill is used the haired putty should only be ground sufficiently to ensure mixing. Longer grinding destroys the hair. Lime putty should be run some time before it is used, to avoid blisters.

This mixture will be found to answer equally well for ceilings as for partitions. If the sand is very sharp use only six bushels of sand for covering the lath, and when sufficiently set follow with eight bushels of sand for floating (or straightening). When no mill is used it is sometimes preferred to make up a fat coarse stuff, with plenty of long hair, and to mix this with the selenitic lime and sand in the proportion of one part of coarse stuff to three parts of selenitic lime and sand, well larrying the whole together."

"*Setting Coat and Trowelled Stucco.*—For common setting or finishing coat of plastering the ordinary practice of using chalk lime putty and washed sand may be adopted. But if a very hard face is required selenitic lime, having been first passed through a 24 × 24 mesh sieve (to avoid the possibility of blistering), may be used in the following proportions: Three parts lime putty, two parts washed sand, one part selenitic lime. This should be treated as trowelled stucco; first well hand floating the surface and then well trowelling. A very hard surface is thus produced.

It is recommended that the workmen be supplied with suitable measures for the lime and sand to ensure that the

proportions be adhered to. The want of this frequently leads to unsatisfactory results.

Selenitic lime must be kept perfectly dry until made into mortar for use.

It is of importance that the mode here indicated of preparing the mortar, etc., should be observed, viz., well stirring the selenitic cement into the water before mixing it with the sand or other ingredient. This is the only point in which the preparation differs from that of ordinary mortar.

Selenitic lime should not be used in conjunction with gauged stuff for cornices, screeds, etc.

The sand or other ingredients should be always clean and free from loam.

No more selenitic mortar should be gauged than can be used in the same day.

Finely ground burnt clay (ballast), or cinders, or stone chippings, as a substitute for sand, in whole or in part, can be used with great advantage in every description of work. Selenitic plastering on walls can be finished in fine weather by the above processes, as two-coat work in twenty-four hours; while the ceilings can be floated soon after the application of the first coat, and be set in forty-eight hours, but the time depends upon the state of the atmosphere.

Selenitic cement mortar, with five parts of sand, will be found to set harder and more quickly than common mortar with two or three parts.

Selenitic blue lias is very superior to that prepared from the ordinary grey lime, etc., for all purposes."

Puzzolana.—This is a volcanic substance found at Puzzola, near Naples, and in other parts of Italy, and consists of a compound of alumina and silica and traces of some of the metallic oxides, lime, potash, and magnesia. It is found, if mixed with preferably lias limes, to produce a hydraulic cement with a considerable compressional and adhesive value. This was used by Smeaton in the construction of

the lighthouse built by him on the Eddystone Rock. Puzzolana mortar is inferior to that made with manufactured Portland cement, and the expense of importation prohibits the use of puzzolana. An artificial puzzolona is made and largely used by grinding old well-burnt bricks and tiles, and adding to lime in lieu of sand to make mortar.

Trass is a similar material to puzzolana, but is obtained from Andernach, in Germany.

Keene's Cement is used as a finishing coat in plastering and is prepared by mixing gypsum with a solution of alum, and then baking it to drive off the water. It is made in two qualities, the coarse and the superfine, and where applied as a plaster sets very hard within a few days, and is suitable for skirtings, angles, etc. The superfine is white and is capable of receiving a high polish; the coarse is of a pinkish tinge, it will not take such a good polish, but sets with a very hard surface. Where applied to brickwork the rendering coat must be in Portland cement.

Parian Cement is a white cement made by mixing gypsum with borax, and then calcining. It is made in two qualities, coarse and superfine. This cement sets rapidly in four or five hours, does not effloresce, and forms a translucent hard surface. It is used for large surfaces, as it works freer though not fatter than Keene's or Martins' cements.

Martins' Cement is a white cement made by mixing gypsum with carbonate of potash, hydrochloric acid being sometimes added; it is made in three qualities—coarse, fine, and superfine. It will cover, bulk for bulk, a greater surface than either Keene's or Parian cements.

Keene's, Parian, and Martins' cements are used for internal plastering work.

Roman Cement is a natural cement prepared by burning at a low temperature nodules found in the London clay, and in the shale beds of the lias formation.

It contains about 40 per cent. of clay, is of a rich brown colour, and weighs, when ground, about 75 lbs. per bushel. It is kept in barrels, as on exposure to the atmosphere it absorbs CO_2 and moisture, and becomes inert. It should, therefore, be used fresh.

It is about one-third of the strength of Portland cement, and is much weakened by the addition of sand, which should never be used in a greater ratio than 1 to 1.

It sets very rapidly, usually in about fifteen minutes after mixing, and for this reason should only be mixed in small quantities as required. It is chiefly used for tidal and constructional work and where rapidity of setting is a necessity. It is now almost entirely supplanted by Portland cement for all works.

Medina is a similar cement to the Roman; it is lighter in colour, and answers the general description of the above. It attains a greater strength just after setting, but its final strength is not so great as Roman.

Harwich, Sheppey, Calderwood, Whitby, Mulgrave's, and Atkinson's are all natural cements, slightly differing in colour and characteristics, but very similar to the Roman.

Portland Cement.—A good Portland cement should contain approximately about 60 per cent. of lime, 20 per cent. of silica, and 5 to 10 per cent. of alumina, and small quantities of alkalies, oxides, etc.

On the Thames and in some parts of the Medway chalk and river mud are the raw materials used, and usually some form of limestone rock is employed with the addition of clay. The usual process of manufacture is as follows:—Chalk and clay are combined in a wash mill, warm water being added to facilitate the combination, which is known as slurry. It is necessary at this stage to test if the mixture will make a good cement. This is done by taking a small quantity in a test-tube, and adding hydrochloric acid (HCl), then heating till the mixture is dissolved, and the inert

matter is precipitated. On cooling a jelly is formed; if stiff, it is indicative that the mixture, with proper manipulation in the after processes, will turn out a good cement; if weak, it usually indicates that one of the ingredients must be augmented. This test also holds good if applied to hydraulic limes. When the slurry is properly formed, it is elevated and caused to flow by gravitation into settling tanks. The solid portion of the slurry is precipitated, the water is drawn off, the compound is then taken and placed on a drying floor, where all moisture is driven off. From there it is taken and placed in the kiln, where it is burnt into clinker. On being withdrawn from the kiln it is sorted, the underburnt clinkers being put back in the kiln and reburnt. The remainder is crushed and passed successively through mills of various degrees of fineness; it is finally passed over a long rocking sieve, where the powder that passes through falls upon a revolving leather belt, which conveys it in a small stream into a cooling shed. The particles that do not pass through the sieve are reground.

Imperfect combinations of the raw materials or too much lime will produce a blowing cement; too much clay produces a contracting and quick-setting cement; overburning produces slow setting, and lightly burning produces quick setting.

The finer a cement is ground the less will it weigh, and at the same time it will be stronger; consequently the weight per striked bushel and the fineness should be considered together in judging of the quality of a cement.

(*a*) *Grinding.*—At least 75 per cent. of the cement should pass through a sieve having 2,500 holes to the square inch (50 holes per inch lineal).

(*b*) *Weight.*—The cement should weigh from 110 to 115 lbs. per striked bushel; the fineness of grinding should be considered in relation to the weight; the finer a cement

is ground the less is its weight, but at the same time if it is fine and heavy it will be stronger.

(*c*) *Colour.*—Good cement is grey, or of a greenish-grey colour; a brown or earthy colour indicates too much clay, which would produce a quick-setting and contracting cement; a coarse bluish-grey cement would be over-limed and likely to blow.

(*d*) *Tensile Strength.*—Average 350 to 400 lbs. per square inch seven days after being made in a mould, and immersed in water during the entire interval.

(*e*) *Test for Coolness.*—If the cement contains too much lime, or is underburnt, or not properly freed from unslaked particles, it has a tendency to crack and swell; this condition will be indicated by cracks and signs of expansion round the edges of the briquettes.

(*f*) *Practical Test.*—Bricklayers plunge their hands in the sacks of cement; if hot, it has not been sufficiently exposed to the air; if at blood heat, it is fit for use.

(*g*) *Bottle Test.*—Portland cement is also tested by mixing a quantity and filling a bottle while still wet. If the cement is too fresh, it will expand and crack the bottle; if it has been kept too long, it will shrink on setting and rattle in the bottle; if it is in a fit condition to be used, it will neither crack the bottle nor shrink on setting, nor rise out of it.

(*h*) *Test for Time of Set.*—The *initial set* of a cement is determined by gauging a pat with the minimum quantity of water, and placing it on a glass slab, and noting the time which elapses between the first addition of water to the cement and the commencement of setting.

The *time of set hard* is determined by means of a similar pat, which, at intervals of every ten minutes or quarter of an hour, is placed under a Vicat needle, which is allowed to rest upon it for about one minute, and when the needle makes no appreciable mark on it the cement may be

considered hard set. The needle has a flat point, and is 0·1 inch in diameter, and is loaded with a weight of three pounds.

(*i*) *Hot Water Test for Soundness.*—The soundness of a cement is determined by subjecting a similar pat to moist heat and hot water in a Faija apparatus. The apparatus is fully described in the "Proceedings of the Institution of Civil Engineers," Vol. LXXV., pages 213—230, and also in the "Proceedings of the Society of Engineers" for 1885, and in other works.

It consists of a vessel in which water is maintained at a uniform temperature of 115° to 116° Fahr. The vessel is covered over, so that the space above the water is filled with a moist heat, which has a temperature of about 100° Fahr.

Immediately the pat is gauged it is placed on a rack in the upper part of the vessel, and is there subjected to the action of the moist heat. In a few hours, or when it is set hard, it is placed bodily into the warm water, and is allowed to remain there for about twenty hours. If on examination after this treatment the pat is found to be perfectly sound, the cement may be safely used; if, on the other hand, it shows cracks or friability on the edges, further experiments should be made to determine whether this is due to the extreme freshness of the sample or to other causes, not absolutely indicative of a blowy cement.

(*k*) *Specific Gravity* should be not less than 3 nor more than 3·05.

(*l*) *Chemical Composition.*—Approximately about 60 per cent. of lime, 20 per cent. of silica, 5 to 10 per cent. of alumina, together with small quantities of alkalies, oxides, etc.

(*m*) *Storage.*—Portland cement is received in bags or casks; it should be spread out to a moderate depth for a month or so on a wooden floor, and should be occasionally turned over, in order that the particles may become thoroughly air-slaked and cooled

(n) Mixing and Using.—The cement should be mixed with as little water as possible, and used immediately afterwards, and on no account be left to commence setting or be worked up a second time. The materials to be cemented together should be clean, free from loose particles, and well soaked in water before use in order that the water may not be drawn out of the cement by absorption.

SPECIFICATIONS.

The following are typical specifications :—

(*a*) War Office.—" The cement to be Portland, and

I. To be fine enough to pass a sieve of 2,500 meshes per square inch, without leaving more than 10 per cent. behind.

II. When made up neat and filled into a glass bottle or similar article, and struck level with the top, it must not, in setting, crack the vessel nor rise out of it, nor become loose in it by shrinking.

III. When made up neat and made into moulds, it must, after seven days immersed in water, be capable of maintaining a breaking weight of 400 lbs. per square inch of section, and when made into cakes $\frac{1}{2}$ inch thick, and after immersion any length of time, show no signs of cracking, swelling, or shrinking.

The immersion in water to commence as soon as the cement blocks can be removed from the moulds, which must not exceed twenty-four hours after the mould has been filled.

N.B.—When there is not sufficient time to employ No. III. test, the following weight test will be substituted :—

IV. To weigh not less than 110 lbs. per striked imperial bushel, filled into the measure as lightly as possible, by sliding it slowly down an inclined board or trough, the bottom edge of which is to be kept slightly above the surface of the cement as it rises in the measure."

(*b*) London School Board.—" The Portland cement to be of the best quality, ground extremely fine, to pass a sieve

of 2,500 mesh to the square inch without leaving a *débris* of more than 10 per cent., and to weigh not less than 110 lbs. per striked bushel (filled into a bushel measure as lightly as possible), and capable of maintaining a tensile strain of 350 lbs. per square inch seven days after being made into a briquette of the usual form, the specimen being immersed in water as soon as it has set, and so left during the interval of seven days."

The striked bushel is a measure with a capacity of 1·28 cubic feet. Twenty-one of these bushels nearly equal one cubic yard.

CHAPTER XII.

CONCRETE.

Concrete is an artificial stone made by mixing lime or cement with small pieces of stone, brick, or other hard substances, and water in such a ratio as to allow of the stones becoming embedded and entirely surrounded by the cementing material, the whole forming on setting a perfectly homogeneous mass.

Uses.—Concrete is used in foundations, walls, floors, staircases, and roofs, for which it is eminently suitable. The composition varies according to the purpose for which the concrete is to be used; heavy concretes with a high crushing resistance are employed for foundations, retaining walls, and engineering works generally, whilst the lighter mixtures are preferable for floors, staircases, and roofs.

Constituents.—Concrete is composed of two parts—first, the matrix; secondly, the aggregate.

The matrix is the cementing material, which may be either lime or cement. If lime be used, it should be of the kind known as hydraulic, finely ground. Blue lias is the best hydraulic lime produced in this country for concrete. Roman cement is sometimes used for tidal works on account of its quick-setting properties. It should be used fresh, or the concrete made from it will be of an inferior quality.

Owing to the great improvement made in the manufacture of Portland cement in recent years, limes and the

natural cements have been almost superseded for concrete works, the superior setting qualities, together with the greater uniformity in resistance where large quantities are used and its great strength, renders Portland cement much more reliable as a matrix.

Aggregate.—The aggregate may be of any of the following materials:—Broken stone, broken brick, ballast, burnt clay, coke breeze, or any other hard or imperishable substances. The pieces should be no larger than will pass through a 1½ inch to 2 inch mesh, clean and free from all argillaceous or earthy matters.

Broken stones or bricks are considered to be better than ballast for aggregates because the former are more angular and the surfaces are rougher, and therefore in a better condition to adhere to the matrix; the pieces also fit more closely together, and do not require such a large proportion of the matrix.

The aggregate should be wetted before mixing with the matrix, otherwise it will absorb the moisture from the matrix and thereby destroy the cohesion of the mass.

Mixing.—Great care should be taken in the mixing of concrete to keep the mass free from all earthy matters. To accomplish this, the compound should be mixed on a wooden platform at least 10 feet square, slightly raised above the ground level. The aggregate is then shovelled on the platform into a measure, which consists of a box with four sides only.

A small and similar box (the cubic content of which bears the same ratio to the content of the large measure as the matrix bears to the aggregate in the concrete to be mixed) is placed on the aggregate before the large measure is removed. The matrix is then measured, and the two boxes, which are bottomless, are removed, leaving the constituents in a conical-shaped mound on the platform; the compound is then turned over twice in a dry condition, and lastly, for

a third time, water being added by means of a can with a rose head. The mass, being then thoroughly mixed and hydrated, is shovelled into barrows or pails, transported to the place required, and gently tipped into position, and consolidated by being beaten with shovels or beaters.

Reduction in Bulk.—The dry materials of which concrete is composed, when mixed with water and shot into position and beaten, become reduced in bulk, owing to the pieces of the aggregate getting packed closer, the average amount of the shrinkage being about $\frac{1}{3}$ of the original total bulk. This important point should be noted in estimating the quantities for concrete work.

Selection of Aggregate.—The aggregates for concretes vary for the parts of the building for which they are intended, as they are required to satisfy different conditions.

Foundations.—The object of concrete in foundations is to distribute the superincumbent weight over a greater area of ground than would be the case if the wall were built directly upon the subsoil. The primary stress, therefore, that it has to resist is compression, and for this no better material than ballast, which is practically incompressible, could be found. But if the ground be uneven or variable in its strength, the concrete may be called upon to act as a beam, as it would rest upon the hard places and tend to settle under the weight over the softer parts. A certain amount of tensile strength is in this case needed, and a material which has a higher adhesive value than ballast, such as broken stone or broken brick, should be employed.

Walls.—Walls are subject to compressive and to bending stresses; in many cases the bending stress being greatly increased by the wind. Walls depend upon their mass and the cohesive strength of their parts for their stability; therefore the concrete for walls requires a larger amount of

matrix than is requisite for foundations, and it is necessary for the aggregate to be of some material capable of bonding or interlocking, such as broken bricks or broken stones. Walls are also subject to injury by fire; therefore the material must be capable of being heated and suddenly cooled without having the tendency to fly to pieces, or deteriorating to such an extent as to render it dangerous. Portland cement is the best matrix to comply with the above condition, and broken fire or other sound bricks are the best aggregates for the same.

Floors.—Concrete for floors should be light, strong, and fire-resisting, as floors are subject to cross stress, due partly to the loads applied and to their own weight, and are also called upon to resist the action of fire.

Portland cement is the best matrix, but plaster of Paris or gypsum has been largely used for this purpose; the latter forms a fairly strong concrete under ordinary conditions, but is liable to failure when suddenly cooled after heating.

The aggregates mostly used for floors are broken fire-brick, coke breeze, ash breeze, and pumice-stone. Fire-brick is chosen for its refractory qualities, and broken hard stocks are also largely used for fire-resisting purposes; ash breeze and pumice-stones are also good aggregates, as they are eminently fire-resisting, and in addition to which they are very light. Coke breeze is very light, but is unsatisfactory to resist fire compared to the other aggregates previously mentioned.

Stairs.—These have to satisfy the same conditions as floors, and in addition have often to be fixed as cantilevers, and must be tough and hard to resist wear. To resist the tensional stresses the concrete is used with iron; to resist wear, aggregates of a hard nature, such as granite chippings, are employed.

Roofs.—The concrete for roofs and domes, not being

required to support any external loads, but only for fire-resisting purposes, should be formed of the lighter aggregates, pumice or coke breeze, the latter being considered the better, as it affords opportunities for fixing the covering.

The undermentioned table is a result of experiments made by Mr. Webster, and given in the "Minutes of Proceedings of the Institution of Civil Engineers" (1890-1891), and may be useful in selecting the best fire-resisting concretes :—

	Nature and Proportions of Materials in Concrete Briquettes.	Average Weight per Cubic Foot.	Tensile Breaking Weight per square inch at Temperature of 60° Fahr.	Tensile Breaking Weight per square inch after being Heated & Quenched.
		lbs.	lbs.	lbs.
1	Neat Portland Cement	124·6	554·6	117·2
2	1 part Cement, 1 part Sand ...	120·9	448·0	93·0
3	1 ,, ,, 3 parts ,, ...	111·2	100·8	18·7
4	1 ,, ,, 5 ,, ,, ...	109·7	74·6	15·0
5	1 ,, ,, 4 ,, iron furnace slag	163·08	108·1	23·06
6	1 ,, ,, 4 ,, broken fire-brick	95·04	84·4	30·5
7	1 ,, ,, 4 ,, pumice-stone	64·8	94·58	38·3
8	1 ,, ,, 4 ,, coke breeze	71·65	69·9	39·06
9	1 ,, Plaster of Paris, 4 parts broken fire-brick	89·6	66·8	10·3
10	1 ,, Plaster of Paris, 4 parts pumice-stone	55·6	57·4	3·4
11	1 ,, Plaster of Paris, 2 parts furnace slag	148·0	223·3	6·9
12	1 ,, Plaster of Paris, 2 parts broken fire-brick	106·9	167·5	15·7

The following tables are the result of a series of experiments made by Mr. Grant to obtain the crushing strengths

of Portland cement concrete with the matrix in various ratios:—

Table No. 1.—Size of Blocks, 6in. × 6in. × 6in. Moulded Nov. 6th, 1867; tested Nov. 6th, 1868. One part of Portland cement, by measure, to eight parts of the aggregate, the blocks not compressed.

	Kept in Air.	Kept in Water.
Portland Stone	24½ tons	19½ tons
Granite	14½ ,,	13½ ,,
Flints	14 ,,	12½ ,,
Ballast	12½ ,,	11 ,,

Table No. 2.—Size of block, 6in. × 6in. × 6in. Moulded Nov. 6th, 1867; tested Nov. 6th, 1868. Composed of one part of Portland cement to six parts of aggregate.

	Kept in Air.	Kept in Water.
Portland Stone	30 tons	23 tons
Granite	24½ ,,	15½ ,,
Flints	15½ ,,	15½ ,,
Ballast	18¼ ,,	17 ,,

Table No. 3.—Size of block, 12in. × 12in. × 12in. Kept for one year. One part of Portland cement to ten parts of aggregate.

	Kept in Air.	Kept in Water.
Portland Stone	72½ tons	78 tons
Granite	50 ,,	60½ ,,
Flints	70 ,,	98 ,,
Ballast	48½ ,,	48 ,,

Transverse Strengths of Concrete Beams.—The following table gives the calculated values of C based upon the experiments of the stated authorities:—

Portland Cement.	Sand.	Aggregate.	Age in Days.	Breadth.	Depth	Clear Span.	No of Tests.	Loaded at.	Average Breaking Weight.	Reduced Breaking Weight at Centre.	One-half Weight of Beam between Supports.	Total Central Load.	Constant per square inch (Calculated Value of C In cwts.).	Authority.
				Ins.	Ins.	Ins.			Cwt.	Cwt.	Cwt.	Cwt.		
1	0	4 clean breeze	43	30	6·5	59	1	Central, 16″	66·32	57·32	2·12	59·44	4·15	C
1	0	4 broken brick	43	30	6·0	59·5	1	Central, 16″	40·52	35·07	2·53	37·6	3·11	C
1	0	5 shingle	139	12	12	36	1	Centre.	85·52	85·62	1·77	87·39	2·73	D
1	2	2 broken stone, 1½″ / 4 broken stone, 3½″	90	12	12	36	3	Central, 6″	52·5	48·12	1·76	49·88	1·56	B
1	2	6 broken stone, 1½″	90	12	12	36	3	Central, 6″	40·83	37·43	1·76	39·19	1·22	B
1	0	9 shingle ...	95	12	12	18 36	1 1	Centre	83·60 38·33	83·06 38·33	0·77 1·53	83·83 39·86	1·31 1·24	D

Authorities:—C, Col. Crozie; D, Darnton Hutton; B, John Kyle.

Transverse Strengths of Concrete Beams based upon Seddon's Experiments.—Sutcliffe applies the following formulæ to the results obtained by Col. Seddon on slabs supported all round and uniformly loaded with layers of bricks. In calculating the value of C it is assumed that the strength of slab No. 4, which is nearly square, is 20 per cent. less than if the edges had been fixed, and that of the remaining slabs 25 per cent. less

Sutcliffe suggests that the strength of a square plate fixed at the ends and uniformly loaded may be calculated from the following formula based upon Grashof, where

w = breaking weights in cwts. per square foot
L = length of each side in feet

t = thickness in inches
W = total load on slab

$$w = 4C\frac{t^2}{L^2}$$

but as total load on square slab uniformly loaded = $w \times L^2$

$$w L^2 = 4C\frac{t^2}{L^2} \times L^2$$

$$W = 4C\,t^2$$

The formula for supported square plates uniformly loaded may be taken to be ·8 of the strength of the square slabs uniformly loaded, fixed at edges; therefore this will be

$$w = 3{\cdot}2\,C\frac{t^2}{L^2}$$

The strength of rectangular plates fixed at the edges and uniformly loaded may be calculated from the following formula, where B = breadth of slab in feet.

$$w = 2C\frac{L^4 + B^4}{L^4} \times \frac{t^2}{B^2}$$

Composition.				Length between Supports.	Breadth between Supports.	Thickness.	Age in Days.	Breaking Weight per square foot.	Weight of Slab per square foot.	Total Breaking Weight per square foot.	Calculated Value of C.
Number.	Portland Cement.	Sand.	1-inch Crushed Bricks.								
				Ft.	Ft.	Ins.		Cwt.	Cwt.	Cwt.	
1	1	0	4	14·5	6·75	6	7	3	·54	3·54	2·85
2	1	0	4	"	"	"	14	2·76	"	3·30	2·66
3	1	0	4	"	"	"	21	8·88	"	9·42	7·58
4	1	0	4	"	13·5	"	"	1·07	"	1·61	2·90
5	1	·75	3	"	6·75	"	14	2·51	"	3·05	2.45
6	1	·75	3	"	"	"	21	2·84	"	3·38	2·72

An example illustrating the use of the above is given in the Chapter on Foundations.

Specifications for Concrete.

(*a*) War Office.—The concrete to be made in the proportion of 1 part Portland cement and 6 of clean Thames ballast or other approved material broken to $1\frac{1}{2}$-inch gauge and 1 part sand as may be found in the ballast. An interval of seven days, or as may be directed, is to elapse between the completion of the concrete foundations and the commencement of the building of the walls upon them.

(*b*) London County Council.—The concrete for foundations must be composed of clean gravel, broken hard brick, properly burned ballast, or other hard material to be approved by the district surveyor, well mixed with freshly burned lime or cement, proportions of 1 of lime to 6, and 1 of cement to 8 of the other material.

(*c*) L.C.C., Walls.—The concrete for walls to be composed of Portland cement and clean Thames or pit ballast or gravel, or broken brick or stone or furnace clinkers, with clean sand in the following proportions:—1 part of Portland cement, 2 parts of clean sand, and 3 parts of the coarse material, which is to be broken up sufficiently small to pass through a 2-inch ring.

ASPHALTE.

Definition.—Combinations of bituminous and calcareous compounds are termed asphaltes, and these may be divided as (*a*) natural, (*b*) artificial. The natural are the asphaltes that are important for use in building works (probably because the bitumen is more thoroughly mixed with the calcareous substances), and consist of asphalte rock taken and pulverised by any method, and thrown in small quantities at a time into melted bitumen equal to 7 or 8 per cent. of the weight of the powder employed, and the

mixture boiled for five or six hours, continuously stirring it by means of revolving agitators; a paste will be the resultant, which, when run into moulds, produces what is known as bituminous mastic or cement.

Chemical Composition.—Natural asphalte is a bituminous limestone of rich brown colour, found in large quantities in France and Switzerland, the component parts of which in its rock condition consist of nearly pure carbonate of lime impregnated with about 10 per cent. of mineral tar; this latter is also known as bitumen. The latter is found sometimes in the free state, sometimes mixed with clay, and at other times cementing together sand and stones. The analyses of bitumen give the following composition by weight:—Carbon, 87; hydrogen, 11·2; and oxygen, 1·8 per cent. respectively (Boussingault), and is a substance of a beautiful black colour, reflecting a reddish light, solid at low temperature, ductile at the temperature of the hand, liquid at about 50° to 100° Centigrade, and is very stable, since it loses scarcely 1 per cent. of its weight when heated to 250° Centigrade.

Coal tar pitch is the residue left on distilling coal tar. It is sometimes used, instead of true or mineral bitumen, for mixing with asphalte. It is, however, brittle, softens more readily under heat, is easily crushed, is altogether inferior, and therefore should not be used.

Characteristics.—The distinguishing properties of asphalte are as follows:—Sanitary, damp resisting, tough, durable, noiseless, non-absorbent, quickly drying after rain, non-inflammable, proof against frost, safe against vermin, can be cleansed easily, slightly elastic (which is good for floors and roofs, as it yields a small amount without cracking), and it is relatively economical. It is not in any way deteriorated by urine, and is laid without joints and seams, and when used for covering ground prevents water from percolating from above or below.

Varieties and Use.—The two varieties in use are (*a*) powdered, (*b*) mastic. The first is the natural rock ground to a powder, and when required for use is subjected to a great heat, and compressed by being rammed when *in situ.*

In the second case, the bituminous limestone is reduced to a fine powder, with which is mixed a certain proportion of grit of uniform size and free from dust. In this state it is by degrees put into large stationary cauldrons, heated by fires, in which sufficient mineral tar to prevent the asphalte calcining has been melted. By means of powerful machinery these are kept constantly agitated for several hours till the whole mass has become thoroughly amalgamated and reduced to a mastic; it is then run into moulds forming blocks, weighing about 125 lbs. This mastic is made in three qualities—the fine, fine gritted, and coarse gritted. The fine, not having any admixture of grit, is employed for magazine floors, and in special cases as a cement for making very close joints in brickwork.

The fine gritted is used as a covering for roofs, arches, linings of tanks, as a cement for brickwork, and for running the joints of stones. The coarse gritted, containing a larger grit and greater quantity than the former, is used for flooring and paving, and where great strength of work is needed, such as gun-shed floors, tun-room floors, margin of stable floors, and in gateways for heavy carriage traffic. These mastics, and more especially the first two, are ductile, and readily yield without cracking to any change likely to take place on the surfaces upon which they are laid; this makes them specially suitable for foundations, floors, and roofs.

The mastic blocks are brought to the works, they are then broken up, melted in cauldrons, spread on the site, screeded to required thickness, and rubbed and finished with hand floats to a smooth surface. This is good for

foundations, floors, roof coverings, and building work generally.

Plates are often cast horizontally, and then placed in a vertical position and jointed to form skirtings.

Precautions.—The principal points to be attended to in all works in asphalte are the following:—The foundations must be solid, the concrete or brickwork must be dry before the application, the asphalte must be very hot, and the joints made to perfectly adhere to one another. To prevent any failure of the joints in exposed positions (such as would occur in roofs and vaults, where it is all-important to have perfect joints), that part of the concrete parallel to the joint should be scraped out to the extent of 3 inches, and to a depth of $\frac{3}{8}$ of an inch, and filled in with a layer of asphalte. Upon, and in the centre of this layer, the joints of the upper coat should be made to meet.

Repairs.—When any part of the asphalte needs renewal, it may be re-melted and re-laid.

The best mode of effecting this is to pour over that part of the old work requiring removal, some hot asphalte, which latter needs to remain a short time and then be removed.

By this means it is softened, and may, without danger of fracture to the other parts, be readily cut up with a stiff knife.

In every case great care must be taken to make good the foundation and cleanse the edges of the asphalte remaining, which should, when heated, as before explained, be cut square to a straight edge that the repairs may be neatly executed.

Noted Asphaltes.—The following are considered as the best asphaltes in the market:—The Seyssel (known as Claridge's Patent Asphalte), obtained from the Jura Mountains, in France, and largely specified for building works; and the Val de Travers, obtained from the mines

at Neuchâtel, Switzerland, immense quantities of which are used in constructing roadways.

Artificial Asphaltes.—Artificial or British asphaltes are formed of an admixture of pitch, chalk, sand or sawdust, and ground iron slag, heated and laid in a semi-fluid state. These are, as already stated, considerably inferior to the natural asphaltes.

Hygeian Rock Composition is a bituminous cement, the constituents of which are not made known by the patentee, W. White, of Abergavenny, Monmouthshire. It is laid similarly to asphalte, and is considered effective and economical for horizontal or vertical damp-proof courses. It is claimed, when used vertically in the body of a brick wall, to impart a strength equal to a wall of double its thickness.

Its characteristic properties are that it is damp proof, and to a great degree non-conducting and vermin proof, it has considerable adhesive strength to brickwork, and is especially applicable for making damp-proof water tanks or cellar walls, and is laid for about half the cost of Seyssel asphalte.

CHAPTER XIII.

BRICKS.

Definition.—Bricks are an artificial kind of stone, made of burnt or baked argillaceous or clayey earth, and the quality of the bricks depends upon (*a*) the chemical properties of the earth, (*b*) the preparation of the earth, and (*c*) the different degrees of burning or baking.

Composition. — The following is approximately the chemical composition of a good brick-earth : — Silica, three-fifths; alumina, one-fifth; iron, lime, magnesia, manganese, soda, and potash forming the remaining fifth.

Clay, or silicate of alumina $(Al_2O_3)_x . (SiO_2)_y . (H_2O)_z$, forms the bulk of brick earths. It possesses the property of plasticity when damp, but upon the application of sufficient heat it gives off its water, losing its plasticity and becoming permanently rigid, and by no known process can its plasticity be restored. It contracts and warps during the process of burning.

Silica (SiO_2) is present, either chemically combined with alumina and water or free, in the form of flint and sand. Its presence in clays produces hardness, resistance to heat, durability, and prevents shrinkage and warping. An excess of silica causes bricks to be brittle.

Lime ($CaCO_3$), when present in brick-earths, acts chemically in burning as a flux, causing the particles of the bricks to unite, producing greater molecular strength, and in small quantities diminishing contraction. An

excess of lime causes the bricks, in burning, to melt and lose their shape.

Magnesia (MgO) influences the colour of bricks.

Iron influences the colour of bricks, but if occurring in clays, as iron pyrites (FeS_2), it should be carefully removed, otherwise it will oxidise in the brick, crystallise, and split it to pieces.

Clays often contain various salts, and those taken from the sea-shore or near salt formations contain a quantity of common salt, which renders the clays unfit for the manufacture of bricks, and when in excess acts as a flux in burning, causing the bricks to warp and twist, in addition to which such bricks absorb atmospheric moisture for a considerable time; the dampness causes efflorescence, which is very noticeable on new work.

Analyses.—The following analyses give an idea of the proportions of the chemical elements in some of the brick-earths. Nos. 1 to 7 are from Abney, No. 8 from Knap.

	1	2	3	4	5	6	7	8
	Fire-Clays.		Ordinary Clays.					
	Dinas.	Stourbridge.	Loam.	Blue Clay.	Burham Clay.	Terra-Cotta Clay.	London Brick Clay.	Marl.
SiO_2	86·2	63·4	66·7	46·5	42·92	75·2	49·5	43·0
Al_2O_3	2·3	23·2	27·0	38·0	20·42	10·0	34·3	
Fe_2O_3	·3	1·9	1·3	1·0	5·0	3·4	7·7	3·0
CaO	1·0	—	·5	1·2	10·79	1·2	1·4	26·04
MgO	—	·9	—	—	·07	trace	5·1	3·5
Alkalies or Alkaline Chlorides ...	—	—	—	—	·33	·5	—	—
CO_2	—	—	—	—	8·12	—	—	20·46
H_2O	—	—	—	—	6·68	5·9	—	4·0
Organic Matter ...	10·0	10·0	5·0	13·6	5·01	3·7	1·9	—
	99·8	99·4	100·5	100·3	99·34	99·9	99·9	100·0

Very few brick-earths are in such condition as to allow of their being used without some special preparation. They are practically classified as plastic or strong clays, loamy clays, and marly clays.

Plastic or strong clays, known to the brickmaker as foul clays, contain silica, alumina, and but a very small proportion of lime, magnesia, soda, or other salts, and are sometimes described as pure clays. For the manufacture of bricks these clays require the addition of silica and lime.

Loamy or mild clays contain quantities of free silica, and are known as sandy clays. To these lime is frequently added.

Marls, or calcareous clays, contain a large proportion of lime, make good bricks, and are frequently used without the addition of other substances, but lime or sand is added if the natural earth is deficient in these compounds.

Malm, or washed earth, is a prepared marl, in which the quantities of the constituents are proportioned to give the best results, where bricks of a specially good quality are required, The brick-earth is ground to a pulp in a wash mill and mixed, to the consistency of cream, with chalk previously ground. It is then passed through a screen or grid, which excludes from the mixture any large particles or stones, and ensures a fine division of the material, which is then conducted into settling tanks or pits. The particles are allowed to settle, and most of the excess of water is run off and a large portion of the remainder evaporates. The resulting pulp is known as malm. At this period the breeze necessary for the proper burning of the brick is spread over the compound.

Frequently malm is mixed with a proportion of ordinary unwashed brick-earth; the product is termed "malmed earth."

Test for Clays.—The brickmaking quality of a clay is usually ascertained by making a brick out of the clay in

question, and treating it exactly as other bricks are treated, by firing it in a brick-kiln. If the brick does not come up to the required standard, chemical analysis will suggest what might be added to improve the earth.

The treatment of brick-earths varies in different brick-yards. The operations are in general as follows, and may be performed by hand or machine: 1st, the preparation of the brick-earth; 2ndly, the moulding; 3rdly, the drying; 4thly, the burning.

The following description of the manufacture of three classes of bricks will include the chief methods of brick-making, viz., (1) the hand-moulded clamp-burnt bricks, commonly known as stocks; (2) the machine-made, wire-cut, kiln-burnt; (3) the machine-made pressed, or hand-moulded, kiln-burnt bricks.

Hand-moulded Clamp-burnt.—For this method the earth is subjected to the following processes: unsoiling; clay digging; stone picking, or washing and screening; addition of chalk, sand, and breeze as required, and weathering; mixing; and tempering in a pug mill.

Unsoiling consists in removing the mould, or top, which is often used for re-soiling exhausted workings. The vegetable mould is known as Encallow, and the operation of removing as Encallowing.

Clay digging is usually performed in the autumn, when the clay is excavated and heaped up to the height of several feet on a levelled piece of ground prepared to receive it, any stones being carefully picked out by hand.

A layer of brick-earth is spread upon the ground, upon which is placed a layer of breeze, and then a layer of chalk, which latter has been previously broken up and mixed with water in a wash mill. This series of layers is repeated till the heap is 5 or 6 feet in height. It is then left through the winter months to be disintegrated and mellowed by the frosts.

An alternative process, where a better class of brick is

required, is to wash the earth and chalk, if required, together in a wash mill. The resulting compound, with a considerable quantity of water, is passed through a grid to ensure the particles being in a fine state of division; it is then conducted to settling pits, from which the excess water is removed. When the material is sufficiently firm, a layer of breeze to the required amount is spread over the top, and left during the winter to weather.

In the spring, the earth which has been left during the winter to weather is mixed, the heaps being cut in vertical sections to ensure the uniform distribution of the various materials throughout the mass. After being turned over two or three times it is wheeled away in barrows, to be tempered.

The object of tempering is to knead the earth into the proper condition for the moulding process. The usual method (when only comparatively small quantities are required) is to turn the clay over two or three times, kneading and battering it with shovels, and picking out any stones that may remain. Horses or men tread over the same, making the clay into a homogeneous mass. Where the demand for bricks is sufficiently great, the clay is tempered by being passed through a pug mill—a machine consisting of a circular stationary tub with a revolving vertical spindle, to which are keyed a number of knives, which, by their motion, cut, knead, and force the clay gradually through the pug mill, fitting it for the immediate use of the clot moulder.

Moulding.—The object of moulding, which is performed by hand, is to give the brick-clay a definite shape.

The operation of hand moulding consists in placing a wooden or iron box termed a mould, about 10 in. × 5 in. × 3 in. (if the dimensions of the burnt brick are to be $8\frac{3}{4}$ in. × $4\frac{1}{4}$ in. × $2\frac{5}{8}$ in., as the clay generally shrinks about one-tenth in all directions), without top or bottom,

over a stock-board with a fillet or *kick*, about 7 in. × 2 in. × $\frac{3}{8}$ in., fixed upon it, and forming a projection upon the stock-board, which is secured to the moulder's bench. The mould is either (1) wetted or (2) sanded, so as to prevent the surface of the raw brick from adhering to its sides. The moulder then dashes and presses a clot of tempered clay, which he has immediately before kneaded with his hands, and from which he has removed any stones which may have escaped previous detection. He then takes the strike, which is usually a pine fillet about 16 in. × $1\frac{1}{2}$ in. × $\frac{3}{8}$ in., and draws and pushes off any superfluous clay over and above the level of the sides of the mould.

Drying.—Directly the clay has been moulded the operation of drying commences, the object being the evaporation of all superfluous moisture without damaging the brick—to render it sufficiently hard to be handled without injury, and to enable the raw brick to possess the requisite strength to withstand the pressure caused by stacking in the clamp during the process of burning.

When the method known as slop moulding is employed, the usual routine is for a boy to take the mould and moulded brick from the moulder, and place the raw brick on its bed upon a drying floor, which is slightly convex, and covered by a roof; the bricks are then sprinkled with sand to absorb superfluous moisture. After one day's exposure the raw bricks are placed upon their sides for another day, after which time they are sufficiently hard to be wheeled upon barrows to the hacks. The hacks are long parallel banks, usually 6 inches above the level of the ground, and built of brick rubbish and ashes, or sometimes of agricultural drain pipes at right angles to the length of the hack, and covered with a thin concrete bed, the object of which is to form a smooth horizontal bed thoroughly drained, so as to keep dry and to prevent the damp from rising.

If the method known as sand moulding be adopted, the moulder places a pallet (which is a piece of pine $\frac{3}{8}$ inch thick, and about 1 inch wider and longer than an ordinary brick) upon the raw brick in the mould, then turns the whole over, releases the mould, and places the raw brick on pallet upon a specially made wheelbarrow with springs, so as to reduce the vibration, which is dangerous to the raw bricks; when the barrow is loaded, the bricks are taken and hacked at once.

The bricks are hacked about $\frac{3}{8}$ in. apart (the thickness of a pallet), being laid on a long narrow face and built about seven courses high, their ends exposed to the weather, their wide faces vertical and at right angles to the length of the hack. In that state they remain for about ten days, after which they are scintled, that is, their wide faces arranged vertically and diagonally at an angle of 45 degrees to the length of the hack, with a space of about 2 inches between the bricks, the directions of the successive courses being reversed, so that the wind may get between and more effectually dry them, the whole operation of drying taking from three to six weeks.

During the time of drying, which takes place in the open air, the hacked bricks are protected from the weather by wood framing, covered with straw, matting, canvas screens, or tarpaulins.

Burning.—The object of burning is to drive the water from the clay and thus cause it to lose its plasticity, and to fuse the constituents into a homogeneous body, and to endow it with the necessary degree of hardness to resist compression for the purposes of building, and to vitrify it sufficiently to resist the disintegrating effects of the winter's frosts.

These bricks are burnt in clamps, the construction of the latter being as follows:—The site is raised above the surrounding ground, and, to ensure dryness, is drained.

This surface is paved with a layer of bricks (generally badly burnt bricks from a previous burning), upon which a series of horizontal flues, termed fire holes, are constructed. These flues are filled with faggots; over these, two layers of bricks are laid on edge diagonally, and about two inches apart, the interstices being lightly filled with breeze. Over this a layer of raw bricks on edge is placed close together; over this is spread a layer of breeze, 7 inches in depth; then another course of raw bricks, on which is a second layer of breeze 4 inches in thickness; upon this another course of bricks on edge; then a layer 2 inches in depth above this. The bricks are built in a series of bolts (that is, a thin unbonded wall) to a height of 14 feet. The time of burning is from two to six weeks, according to the number of fire holes and the atmospheric conditions.

The bricks produced by this method are termed stocks.

These are generally employed for the internal parts of the walls of buildings, for which purpose they are eminently adapted, being capable of resisting a great amount of compression, and their surfaces forming a very effective key for plastering. Usually the better qualities of stocks are picked for facings, care being taken that as nearly as possible they should be of one tint, showing well-burnt faces.

Stocks are classified according to their quality as follows:—Malms, Malmed, and Common.

Malms.—Cutters, Best Seconds, Mean Seconds, Pale Seconds, Brown Facing Paviors, Hard Paviors, Shippers, Bright Stocks, Grizzles, Place.

Malmed.—Bright Fronts, Stocks, Shippers, Hard Stocks, Grizzles, Place.

Common.—Stocks, Shippers, Grizzles, Rough Stocks, Place, manufactured from unwashed earth.

1. *Cutters or Rubbers.*—Made from washed earth containing sufficient sand necessary for a burnt brick, which

is required to be easily divided with a brick-cutter's saw. The best are burnt to a state little short of vitrification.

2. *Seconds.*—Similar to No. 1, but uneven in colour.

3. *Facing Paviors.*—Hard-burnt malms of good shape and colour, used for facing of superior walls.

4. *Bright Fronts.*—Similar quality, from malmed earth.

5. *Hard Paviors.*—More burnt; slightly blemished in colour; used for superior paving, coping, etc.

6. *Shippers.*—Sound hard-burnt bricks, imperfect in form; used as ballast for ships.

7. *Stocks.*—Hard, sound, fairly uniform in colour; they are used for the mass of ordinary good work.

8. *Hard Stocks.*—Overburnt, but sound; slightly misshapen, and colour not uniform; they are used in footings and in the body of thick walls, and in positions where the work is subjected to a great compressional stress.

9. *Grizzle.*—Underburnt, but sound and of good form; used for inferior or temporary work, and where not required to resist heavy loads.

10. *Place.*—Underburnt, weak; containing stones, causing them to be very liable to breakage; for inferior or temporary work. Sometimes place bricks are used in the panels of brick-nogged partitions for the purpose of retarding sound.

11. *Chuffs.*—The action of wind, frost, or rain upon bricks while hot, on the outside of clamps, or if the bricks are put into clamps before they are sufficiently dried, causes the bricks to be full of cracks and useless for constructional purposes; such bricks are termed chuffs.

12. *Burrs.*—Lumps of bricks vitrified and run together. They are useful for rough walling, artificial rock work, etc.

Stock Bricks, Machine Made.—Messrs. Eastwood & Co., of Conyer, Kent, have recently introduced a German patent for the manufacture of stock bricks by machinery, with patent drying chambers and kiln. Great care is taken in

the proper admixture of the usual materials, which is run with a large proportion of water into settling pits. After the surplus water has been drained off, and the prepared earth is sufficiently mellowed by weathering, it is then barrowed into the pug mill, and from thence passed to the moulding machine below, where it is pressed into a mould with a capacity for six bricks. Upon removal from the moulds, the raw bricks are placed upon specially constructed trolleys, working upon tram-lines, and conveyed to the drier. This consists of three long chambers, through which the heat is regulated by means of fans, the temperature varying from 45 degrees to 200 degrees Fahr. The bricks by this method are fit for the kiln in 24 hours. For burning they are then stacked upon specially constructed trolleys running upon a tramway. The upper portions of the trolleys for a considerable thickness are formed of fire-brick. These are passed into one end of the kiln, which is a chamber 180 feet long, only slightly larger in section than a loaded truck. It emerges after three days, after having passed through a heat gradually increasing in intensity towards the centre of the kiln, and then decreasing. Fuel is supplied through fire holes in the roof of the kiln. The resultant bricks are more uniform in shape and colour than the ordinary hand moulded brick, and in addition these are turned out at a much greater rate than by the hand process, and the manufacture can be carried on throughout the whole year. There is also great economy, as it is anticipated there will not be more than from 3 to 10 per cent. of grizzles or waste.

Kiln Burnt Red Bricks, Hand Moulded.—The processes through which the brick passes are as follows :—clay getting, washing, weathering, pugging, moulding, drying, burning.

All these processes but the burning are carried out as previously described for malm or washed earth bricks. When the bricks are sufficiently dried they are burned in a kiln.

These kilns consist of four walls, without roofs ; fire holes

are arranged at the base, in which the coal for burning is added. These chambers are made sufficiently large to contain from 20,000 to 50,000 bricks. The bricks are stacked with a space between to allow the fire to permeate the mass. When the bricks are arranged, the fires are applied gradually to drive off the moisture remaining in the bricks. This done, more fuel is applied, and the burning proceeded with. The top layer of bricks is protected by covering with old bricks to economise the heat. The bricks take from two to three days to burn, after which the fires are damped and the kilns allowed to cool gradually. Bricks burnt by this process are far more uniform in colour and regular in shape than clamp burnt bricks. The best bricks are taken from the centre of the kiln; the bottom layers are liable to be fused, those at the top are generally underburnt, soft, and unfit for face work. Kiln burnt bricks may generally be classed as:—Builders' 1st, from middle of kiln. Builders' 2nd, from between 1st and 3rd. Builders' 3rd, bottoms and tops. The earth used is invariably a loamy clay containing a quantity of free silica, and generally the resultant colour is red.

Machine Moulded Wire Cuts.—The operations to produce these bricks are as follows:—Clay getting, stone picking (if necessary), grinding, or weathering and grinding, pugging, pressing and squeezing through an orifice in a strip of about $4\frac{1}{2}$ in. × 9 in. section. It is then cut into 3-inch layers by means of wires arranged in a frame. The usual method of burning these bricks is in a Hoffmann or similar kiln. The Hoffmann kiln is circular in plan, and consists of an annular chamber divided by movable iron shutters into several compartments, usually twelve, each of which is connected by a flue to a central chimney. The bricks as they are moulded are stacked in the compartments; when all are loaded, the kiln is fired in No. 1 compartment, this being divided from the last compartment by an iron shutter.

The flues in all the compartments connecting with the central chimney, with the exception of the last one, are closed. The heat consequently has to traverse the whole circuit of the kiln, and through all the stacks of bricks, igniting one after the other. The heat is thus gradually applied, thoroughly drying the bricks before burning. When the fire has passed on to about the sixth compartment, the first in which the bricks have been burnt is opened, and the bricks when sufficiently cooled are removed. This chamber is then refilled, the iron shutter closed between Nos. 1 and 2 compartments, the flue of No. 1 compartment connecting with the central chimney is opened, the iron shutter between last and first compartment is opened, and the flue in the last compartment connecting with the central chimney is closed. No. 2 compartment is then opened preparatory to emptying. The fire thus continues to travel in a cycle about the kiln.

Machine Made Fletton Bricks.—Of late years large quantities of these bricks have been made in the neighbourhood of Peterborough, the output being at the rate of 8,000,000 per week.

The operations consist of clay getting, drying, grinding, sifting, pressing, and burning.

The clay, which is obtained from the Oxford clay formation and is a dense bluish grey shale, is dug, dried on a drying floor to expel superfluous moisture, and ground in a mill similar to a mortar mill, the receiver revolving and carrying the clay under the rollers. The bottom of the receiver is perforated, which allows the material, when sufficiently ground, to fall through as a coarse powder into a pit beneath. It is then elevated and shot into a revolving circular inclined sieve; the material that is sufficiently fine passes through, the remainder is conveyed back to the grinding mill. The sifted powder falls into a hopper, from whence it is passed to the pressing machine, where, by an

ingenious arrangement, it is measured off and passed under the die, where it is pressed into the form of a brick, and removed automatically from the mould. The bricks are then placed on barrows and stacked in the kiln, which latter is of the Hoffmann type, and then burnt. The time from digging the clay to the stacking in the kiln need not occupy more than 15 minutes, the time taken to burn the bricks usually taking about three weeks. These bricks are of good form, compact, and are useful for all internal work. Their colour, a reddish yellow, is not such as would fit them for the best facing work. For internal work to receive plaster, special bricks are prepared with dovetail-shaped grooves.

RESULTS OF EXPERIMENTS ON SIX FLETTON BRICKS TO ASCERTAIN THE RESISTANCE TO A GRADUALLY INCREASED THRUSTING STRESS, OCTOBER, 1902.

	Description.	Dimensions.	Base Area.	Stress in lbs., when		
				Cracked slightly.	Cracked generally.	Crushed.
		inches.	sq. ins.			
1	Light Red Brick, recessed one side	2·64×8·74×4·18	36·53	89,700	151,200	155,000
2	Do.	2·65×8·70×4·13	35·93	82,200	134,200	134,200
3	Do.	2·62×8·72×4·16	36·27	83,400	120,500	133,100
4	Do.	2·64×8·65×4·23	36·59	83,600	124,500	124,500
5	Do.	2·64×8·73×4·12	35·97	79,600	118,400	122,700
6	Do.	2·68×8·78×4·25	37·31	68,200	113,800	122,100
		Mean ...	36·43	81,117	127,100	131,933
		Lbs. per sq. inch...		2,227	3,489	3,622
		Tons per sq. foot		143·2	224·4	232·9

Bedded between pieces of pine ⅞ inch thick. Recess filled with cement.

The average Fletton brick, when immersed in water for 24 hours, will absorb 20 per cent. of its weight of water.

The usual dimensions of Fletton bricks are $8\frac{3}{4}$ in. × $4\frac{1}{4}$ in. × $2\frac{5}{8}$ in.; weight about 5·6 lbs. each, or, say, $2\frac{1}{2}$ tons per thousand, but there is unfortunately no standard, and many different sizes are made.

The composition of the "Knotts" clay, from which Fletton bricks are made, is more or less as follows:—

Silica	50 per cent.
Alumina	16 ,, ,,
Peroxide of iron	7 ,, ,,
Carbonate of lime	10 ,, ,,
Magnesia	1 ,, ,,
Alkalies	3 ,, ,,
Organic matter	6 ,, ,,
Water	7 ,, ,,
	100 ,, ,,

but varies with the locality and with the depth below the surface from which the clay is taken; the carbonate of lime is chiefly due to fossils, the quantity of which is very variable.

Indications of Processes.—The following hints are useful in determining some of the processes which a finished brick has passed through.

Hand Moulded.—Frog on one side; and no great amount of finish in the form, and porous.

Wire Cuts.—No frogs: wire marks on the beds; regular in form and dense.

Pressed Bricks.—These have some or all smooth faces, sharp and regular arrises, clean frog or frog on both sides, and trade marks in the frog. These bricks are very dense.

Clamp Burnt.—Colour (of the bricks) is not uniform; the traces of the breeze can be seen, especially if the bricks are broken across, when also the internal colour will be noticed to be darker, and the texture slightly vitreous.

Kiln Burnt.—Light and dark stripes upon the sides, caused by the bricks being arranged with intervals between them while burning, the exposed parts being burnt to a light colour, and where resting upon or against another brick to a dark colour. This may be prevented by stacking the bricks upon their front faces in contact while burning.

Colour.—The colour of bricks is affected—

(*a*) By the chemical constituents of the brick earth.

(*b*) By the sand which has been sprinkled upon the raw bricks before being burnt.

(*c*) By the degrees of heat to which a brick has been subjected during the process of burning.

(*a*) The colour is determined chiefly by the quantity of iron present in the clay.

Bricks manufactured from clay free from iron burn white, and such clays, containing but a small quantity of lime, together with iron, give a cream colour.

With a small quantity of lime, but additional iron, a red colour is produced, and an additional quantity of lime gives a brown.

Clays possessing from 8 to 10 per cent. of iron give in burning a blue or almost black colour.

Bricks in burning are exposed to a great heat, and if the clay contain alkalies, and be burnt at a still higher temperature, a bluish green is produced, as in the case of Staffordshire bricks, which, under ordinary circumstances, are red.

White bricks usually contain but the merest trace of iron.

Blue bricks are prepared from earth containing a large proportion of oxide of iron.

Black bricks are made from a similar clay to the blue bricks, but in addition contain a small quantity of manganese.

To obtain a clear bright-red brick the clay should be

free from impurities, and contain a large quantity of oxide of iron, which, by burning, is converted into the red oxide, but not fused.

Magnesia in the presence of iron makes the brick yellow.

In clamp-burnt bricks the sulphur contained in the ashes gives them a yellow or brimstone tint.

(*b*) The sand sprinkled upon the raw bricks before they are burnt is vitrified in burning, and this will to a great extent affect the surface colour, which is but skin deep.

(*c*) As a general rule, the greater the amount of heat to which a brick has been subjected in burning, the darker the tint.

The varieties of bricks in common use in the neighbourhood of London include Stocks, Fletton, Wire Cuts, Gault, Red, Blue, Black, Paviors, Fire Bricks, Salt-glazed, Enamelled.

The first three have been previously described.

Gault Bricks.—These are made from a bluish clay interposed between the upper and the lower greensand. The composition of the Gault Clay varies. Although of a fairly uniform dark blue colour, it contains at times (comparatively speaking) large quantities of the hydrous oxide of iron; at others, a good deal of carbonate of lime is found in combination.

The bricks are all burnt in the kiln—in the former case into a deep red brick or tile of an inferior quality; in the latter, perforated, hard, white bricks are made.

These bricks require great care in burning, for if the calcination of the lime takes place under such conditions that the lime is left in a caustic state, it will slack on exposure to the weather, or when moisture is applied to it.

Suffolk Bricks, called also *White Suffolks.*—These are Gault bricks, and are kiln burnt, being expressly made for

facings, but they are expensive. The best can rarely be obtained in London, being sold in the locality of their manufacture. They have a disagreeable cold hue, rendered still more dull after a few years' wear in a smoky atmosphere. They are not as well burnt as those possessing a somewhat light pink or salmon tint.

Beart's Patent Bricks.—These are Gault bricks, made at Arlesey, near Hitchin, on the G. N. Railway, and comprise the following, ranged according to price :—

(*a*) White Rubbers, which are hand-made, moulded, solid, and equal to the best Suffolks.

(*b*) No. 1, best selected, white facing, pierced brick, are of uniform colour, hard, well burnt, and extensively used for facings.

No. 2, red and pink blended, differing from No. 1 in colour only, are in every way equal to the best made stock bricks.

Red Bricks.—These bricks are made from a loamy clay, in which the sand contains a considerable quantity of iron. and are used as facings. A class of these bricks, upon which special treatment of careful washing, weathering, and tempering of the brick earth has been expended, and which contain an excess of sand above that usually employed, are termed cutters, or rubbers. They can be easily cut to any required shape by means of a brick saw, and in consequence of their fine texture can be rubbed to sharp arrises, and are also suitable for carving. They are largely used for arches and decorative work. The "Fareham Reds," and those supplied by Messrs Blanchard, of Bishop's Waltham, are noted bricks of this class; and also the well-known T.L.B. rubbers, made by Messrs. Lawrence & Co., Bracknell, which are supplied largely to the London market.

Blue Bricks are made from clays containing about 7 to 10 per cent. of oxide of iron. Large quantities of these are made in Staffordshire from the clays in that district.

They are either wire cut or pressed, of a very dark blue colour, highly vitrified, very hard, dense, and capable of resisting great pressures. The same clay, if less burnt, produces a red brick.

They are largely used for engineering works, and for piers where great compressional resistance is required. Special bricks are pressed for coping, channels and paviors.

Black Bricks are made from earths containing a large proportion of oxide of iron, together with oxide of manganese, and burnt at a high temperature, and are especially useful for polychromatic work.

Paviors.—The following are used for the purposes of paving:—Hard Stock Paviors, Blue Staffords, Dutch Clinkers, and Adamantine Clinkers. The first two have already been mentioned.

Dutch Clinkers.—These are very small, kiln burnt at a high temperature, hard; are used for paving, and usually made 6 in. × 3 in. × 1 in.; are vitrified throughout, and sometimes warped.

Adamantine Clinkers.—These are bricks similar to the above, but harder, denser, and heavier. They are of a fine pink-white colour, and present a smooth surface. The edges are sometimes chamfered in order to give a firmer foothold when used for paving. They are made of numerous sections, such as kerbs, channels, etc., and of varying dimensions.

Fire Bricks.—These are so named on account of the resistance they offer when subjected to a very great heat, which resistance depends chiefly upon the relative quantities of silica, alumina, and oxide of iron present in the clay. They are yellow in colour, close in texture, and are made to the dimensions of an ordinary brick. The loam of which they are made is of a yellow colour, rough to the touch, and contains a considerable quantity of sand. They are highly serviceable for furnaces and ovens. They

are made in various parts of Wales and called "Welsh Lumps," at Newcastle, at Poole, at the Hurlford Works near Glasgow, and at Stourbridge. The latter place supplies the London market chiefly, but the material is dear. The Dinas Brick, manufactured by the Ynysmudw Company, near Swansea, resists a heat sufficient to melt the Stourbridge brick.

Salt-glazed Bricks.—These bricks have a thin glaze on their exposed surface, caused by throwing salt in the kiln fire during the process of burning. This is explained in the article on "Stoneware."

Enamelled Bricks.—These have a white, light yellow, or other coloured surface like that of china, this surface being produced by covering a partially-burnt brick with a thin coating of white or other enamel over the required surface, and then re-burning the brick. This is known as biscuit ware.

Enamelled bricks of various colours, including white, are now manufactured by enamelling the raw brick and fixing the tint in one burning. These are more durable than those made by the biscuit process, but the best bricks of this make are expensive, as many are spoilt in burning. These bricks are much used for the sake of cleanliness in lavatories, dairies, etc., and also to reflect light in contracted areas.

Opalite.—This is a vitreous compound made in thin sheets of $\frac{1}{8}$ inch bare in thickness, the front presenting a highly glazed appearance, the back being covered with rough particles of the same material, burnt on to form a key. This material is made of varying dimensions, frequently of sizes of the external faces of bricks, to which they are attached by being bedded on a plaster specially prepared by the patentees. It is prepared in various colours, and is extensively and successfully used at a much less cost for all purposes for which glazed bricks would be suitable.

Crystopal.—Crystopal is a vitreous opaque compound, manufactured in thin sheets about $\frac{1}{8}$ inch in thickness, with a highly glazed surface, prepared in different colours, and similar in essentials to opalite, the chief difference being the key, which with this material consists of a mastic of an elastic nature; it is applied to surfaces of brick, stone, or concrete, which are rendered in cement to form a ground; also to wood surfaces, to which it is secured with a mastic. It is claimed for this material that it does not crack through the differences in expansion and contraction of the different materials, the elasticity of the mastic compensating for these differences.

Characteristics of, and Tests for, Good Bricks.—Regularity of shape, uniformity of size, rectangular faces—only one end and side need be smooth—of uniform texture, compact and free from flaws of every description. The quantity of water absorbed by a brick is a good test of its quality. When saturated they should not absorb more than about 15 per cent. of their own weight of water, they should absorb it reluctantly, and part with it freely at moderate temperatures.

They should be uniformly burnt hard, and give a metallic ring when two are knocked together—a dull sound indicating a soft or shaky brick; should be of a good colour for their kind, sound when broken, tough or pasty in texture, not granular; should require repeated blows before breaking rather than one hard blow; should stand cartage and handling well.

Absorption.—Insufficiently burnt bricks absorb a large quantity of water, and are not durable.

The absorption of bricks varies from one-sixth to one-fifteenth of their weight. The London Stock, Burham Wire Cut, Burham Pressed, and Wire Cut White Gault absorb $10\frac{1}{2}$, 19·0, 19·5 and 19·0 per cent. respectively.

Machinery.—In the manufacture of bricks, where a great

quantity is required, and where there seems a possibility of a regular demand, machinery is largely employed.

By machinery they are produced more cheaply, less labour being required.

Machines used for tempering the clay are called Pug Mills. Grinding machines consist of a pair of horizontal rollers, for crushing small fragments remaining in the clay. If, in addition, the clay is forced through an orifice, and then cut by wire according to the dimensions required, they are known as wire cutting machines.

Still more recently machines have been used for tempering, moulding and pressing into the required form at one operation; that is to say, that the raw clay is placed in the machine, and is taken from it as a pressed brick.

Bricks, after the hand moulding process, are often placed in a hand pressing machine, with the object of correcting the form, and producing smooth faces and sharp regular arrises.

Strength of Bricks.—Bricks are subjected in practice to compression, sometimes to transverse stress, but not to tension, except such as would be caused by wind pressure or other lateral forces.

CRUSHING STRENGTH OF BRICKS (UNWIN).

(Single bricks. Faces made smooth and parallel by plaster of Paris.)

Description.	Dimensions.	Cracked at tons per sq. ft.	Crushed at tons per sq. ft.	Colour.	Remarks.
London Stock, max.	9·2 × 4·3 × 2·8	—	185	—	Twelve from different localities.
,, ,, min.	8·8 × 4·0 × 2·5	84	89	Yellow	
,, ,, mean	9·0 × 4·2 × 2·6	—	121	—	
Aylesford common	8·9 × 4·4 × 2·7	48	183	Pink	

CRUSHING STRENGTH OF BRICKS (UNWIN)—*continued.*

Description.	Dimensions.	Cracked at tons per sq. ft.	Crushed at tons per sq. ft.	Colour.	Remarks.
Aylesford common	8·9 × 4·4 × 2·7	111	228	Pink	
,, pressed	9·1 × 4·3 × 2·7	71	141	Red	Frog
Grantham wire-cut	9·2 × 4·2 × 3·2	—	83	,,	
Leicester ,,	8·9 × 4·5 × 3·2	228	246	,,	
,, ,,	9·1 × 4·2 × 2·8	115	229	,,	
,, ,,	4·4 × 4·2 × 2·7	225	365	,,	Mean of 7 half bricks
Gault wire-cut, max.	8·9 × 4·3 × 3·0	119	198	White	
,, ,, min.	8·7 × 4·1 × 2·7	89	145	,,	
,, ,, mean	8·8 × 4·2 × 2·8	—	178	,,	
Arlesey white, max.	9·1 × 4·2 × 2·9	—	207	,,	
,, ,, min.	8·8 × 4·1 × 2·7	50	107	,,	
,, ,, mean	8·9 × 4·2 × 2·7	—	161	,,	
,, ,, wire-cut	9·0 × 4·2 × 2·7	151	239	,,	
Coventry	4·5 × 4·4 × 3·0	—	256	Red	Half brick
Fletton	8·6 × 4·2 × 2·7	137	203	Pink	
,, ...	8·8 × 4·1 × 2·7	126	169	,,	
,, ...	8·6 × 4·2 × 2·7	199	239	,,	
Glazed brick ...	8·8 × 4·4 × 3·3	69	166	White	Frog
,, ,, ...	8·9 × 4·4 × 2·9	166	174	,,	,,
Kentish stock, max.	9·3 × 4·4 × 2·9	107	127	Yellow	
,, ,, min.	9·1 × 4·3 × 2·8	30	54	,,	
,, ,, mean	9·2 × 4·4 × 2·9	—	82	,,	
Staffordshire blue, max.	9·0 × 4·5 × 3·2	763	807	Blue	Nineteen half bricks
,, ,, min.	8·9 × 4·1 × 2·7	152	296	,,	
,, ,, mean	9·0 × 4·2 × 2·9	—	564	,,	
Stourbridge ...	8·8 × 4·3 × 2·8	157	209	Yellow	
,, ...	9·0 × 4·3 × 2·8	161	242	,,	
,, ...	9·0 × 4·3 × 2·7	—	300	,,	
Red rubbers, max.	10·1 × 4·9 × 3·4	—	93	Red	
,, ,, min.	9·9 × 4·8 × 3·3	36	67	,,	
,, ,, mean	10·0 × 4·9 × 3·4	—	77	,,	
,, ,, three in column, bedded in putty... ...	9·0 × 4·5 × 8·0	—	25	,,	
Terra-cotta block ...	6 sq. in.	—	168		
,, ,, ...	15 ,,	—	139		
,, ,, ...	15 ,,	—	237		
,, ,, ...	6 ,,	—	104		

Strength of Columns of Brickwork.—With piers of brickwork having a height of less than twelve times their least thickness:

	Weight per ft. super at which crushing commences.
	Tons.
Bricks, hard stocks, best quality, set in Portland cement and sand, 1 to 1, three months old	40
Bricks, ordinary well burnt, London stocks, three months old	30
Bricks, hard stocks, Roman cement and sand, 1 to 1, three months old	28
Bricks, hard stocks, Lias lime and sand, 1 to 2, six months old	24
Bricks, hard stocks, grey chalk, lime and sand, 1 to 2, six months old	12

The factor of safety for a working load may then be taken as one-fifth to one-tenth of the above quantities.

Tests of Brick Piers by a Committee of the Institute of British Architects.—Under the direction of a committee, a series of piers of large size were built of five varieties of brick with both lime and cement mortar. These piers were 6 feet in height and generally 18 inches square. The piers of Staffordshire blue bricks were 13½ inches square. The cement mortar was mixed by measure, the proportions being one cement to four washed river sand. The grey lime mortar was mixed in the proportion of one to two. Unfortunately the piers first built were not very well built, or the mortar was not quite satisfactory. The piers of the second and third series were built under more careful inspection and were stronger. The tables on pages 330 and 331 give the results. The ratio of strength of pier to strength of brick has been calculated from the third series.

Ratios of Strength of Brick Piers and Single Bricks.—The

strengh of brick piers built in mortar is often difficult to obtain, but they may be approximately determined by

CRUSHING STRENGTH IN TONS PER SQUARE FOOT.

Mortar.	Age. Months.	Stocks.	Gault.	Fletton.	Leicester Red.	Stafford Blue.
Single brick ...	—	84	189	221	362	780
Sand pier ...	—	—	—	—	15	—
FIRST SERIES.						
Lime	3½	10·4	21·9	—	30·7	74·3
,, ...	10	12·5	21·6	—	34·1	73·7
Cement	3½	14·9	17·8	—	58·5	72·8
,, ...	10	19·7	30·0	—	50·4	82·5
SECOND SERIES.						
Lime	3½	18·3	—	—	—	—
Cement	3½	—	49·6	—	86·4	103·1
THIRD SERIES.						
Lime	5	18·6	31·1	30·7	45·4	114·3
Cement	5	39·3	51·3	56·3	83·0	135·4

RATIO OF STRENGTH OF PIERS TO THAT OF SINGLE BRICKS.

THIRD SERIES.

Mortar.	Age. Months.	Stocks.	Gault.	Fletton.	Leicester Red.	Stafford Blue.
Lime	5	·22	·16	·14	·13	·15
Cement	5	·47	·27	·25	·23	·17

The pier of Leicester red bricks, built dry, with simply a layer of sand in the joints, carried 15 tons per square foot, or half as much as similar piers built with lime mortar tested after 3½ and 10 months old

knowing the ratios of the strength of masses of brickwork to the strength of single bricks.

Unwin, in "Testing of Materials on Construction," gives ratios deduced from the following tests:—

TESTS OF BRICKWORK BUILT IN MORTAR.

Dimensions of Pier.	Composition of Mortar.	Age of pier in months.	Ratio of strength of brickwork in mortar to single bricks.	Authority.
10″ × 10″ × 9·5	1 of lime, 2 of sand	3	0·44	Dr. Böhme, Berlin.
10″ × 10″ × 9·5	7 of lime, 1 cement, 16 sand	3	0·48	
10″ × 10″ × 9·5	1 cement, 6 sand	3	0·55	
10″ × 10″ × 9·5	1 cement, 3 sand	3	0·63	
8·6″ × 8·6″ × 22″ high	1 lime, 2 sand	2½	0·121	Wright and Keele, Toronto.
9″ × 9″ × 24″ high	1 lime, 2 sand	2½	0·292	
8·6″ × 8·6″ × 24″ high	1 Portland cement, 3 sand	2½	0·258	
9″ × 9″ × 24″ high	1 Portland cement, 3 sand	2½	0·684	
12″ × 12″ × 117¼″	1 lime, 3 sand	24	0·07	American Society of Civil Engineers, 1887—1888.
8″ × 8″ × 17″	1 lime, 3 sand	15	0·18	
16″ × 16″ × 121″	1 Portland cement, 2 sand	24	0·11	
12″ × 12″ × 23½″	1 Portland cement, 2 sand	23	0·26	
18″ × 18″ × 72″	1 grey lime, 2 washed river sand	5	0·13	Committee of the Institute of British Architects.
18″ × 18″ × 72″	1 grey lime, 2 washed river sand	5	0·22	
13½″ × 13½″ × 72″	1 cement, 4 washed river sand	5	0·17	
18″ × 18″ × 72″	1 cement, 4 washed river sand	5	0·47	

Tensile Strength of Bricks.—The tensile resistance is given by Professor Rankine as varying from 280 to 300 lbs. per square inch.

TILES.

Definition.—Tiles are thin slabs of brick earth burnt in kilns, used for covering roofs, paving, etc.

Preparation.—The clay is prepared in a similar manner to that for bricks, but all the operations are conducted with greater care, especially in separating all the stones, on account of the thickness required being so small.

Shape.—Tiles for covering roofs are made in many forms and patterns; two of the most generally known and used being the plain and pan tiles.

Plain Tile.—The plain tile is rectangular in shape, the dimensions being $10\frac{1}{2}$ in. × $6\frac{1}{2}$ in. × $\frac{1}{2}$ in. in thickness. These tiles are made with two holes, through which are driven oak pins hanging over laths, or nails through boarding for fixing purposes. The tiles are now often made with small projecting nibs on the top under-edge for hanging purposes; when hung on steep slopes or vertical faces they are nailed in addition.

The tiles are made slightly rounded in their length, the concave surface being kept under, in order that the bottom edge may bite well on to the tile below.

Plain tiles are made in three widths—half tile, tile, and tile and half, the first being used as the end tile of every alternate course to break joint. In many cases where secret gutters are used, or in similar positions, there is a difficulty in fixing a half tile properly, and tile and half tiles are substituted to ensure an efficient fixing.

Special tiles are made to cover hips and valleys, and also to cover vertical angles where walls are weather tiled. Ridge tiles are made either plain or to ornamental patterns, special pieces being moulded for stopped ends, hipped ends, and intersecting ridges, or ridges intersecting with slopes.

Pan Tiles.—Pan tiles are made of a flat S shape, 14 in. × 9 in. × $\frac{1}{2}$ in.; they are originally moulded flat, being bent to shape afterwards; they have a projecting nib on the under-side of the top edge, by which they are hung to the battens. The hips and ridges are covered with segmental tiles bedded in mortar. These tiles when laid have a lap of three inches over the head of the tile immediately below; they do not lie closely together, and for that reason have to be bedded in mortar. Pan tiles do

not form such a good covering as the plain tiles, and should only be used for sheds and workshops.

Paving Tiles.—Paving tiles are usually thicker, varying from ½ to 1 inch, some being made from a similar clay to that for ordinary tiles; others are mixed with various substances to colour them. These are made in 6 in. × 6 in. squares, hexagons, and other geometrical patterns.

Manufacture.—The tiles are manufactured in a similar manner to bricks, going through the processes of clay-getting, tempering, moulding, drying, after which they are beaten to correct their shape, and then baked in a kiln.

TERRA-COTTA.

Terra-cotta is a material made from a refractory brick-earth, carefully selected and prepared; it is usually moulded into blocks, and built to represent ashlar work, being made up to 18 inches in length. The size of blocks of terra-cotta should never be made to exceed 4 cubic feet; undoubtedly blocks the contents of which do not exceed 1 cubic foot are much to be preferred.

Composition.—The following shows the composition of a typical specimen of terra-cotta :—

Silica	75·2
Alumina	10·0
Sesquioxide of Iron	3·4
Calcium Oxide	1·2
Magnesium Oxide	trace
Alkalies and Alkaline Chlorides ...	·5
Water	5·9
Organic Matter	7·7

It will be seen by the large amount of silica and the small percentage of alkaline matter present that the clay will be refractory, the quantity of the latter being just sufficient to cause a vitrified skin or surface, to which the

material owes its durable qualities. The quantities of oxide of iron present, varying from the above amount to 10 per cent., impart the shades of pink and red common to terra-cotta.

Manufacture.—The material is carefully ground, strained and pugged, and, to avoid excessive shrinkage in drying, sand, ground glass, or pottery is sometimes added. The mixing must be conducted with great care to ensure uniformity throughout the mass.

The material is moulded, carefully dried, and then baked. The two latter operations must not be accomplished in a hurried manner, or the material will twist.

The terra-cotta blocks are not made solid, but are built up hollow, the thickness of the sides varying from 1 inch to 2 inches, and have diaphragms or partitions connecting the opposite sides for their support. By this arrangement great thicknesses of the material are avoided, the drying is facilitated, and the surfaces and the interior are more uniform, thereby avoiding fractures, which would otherwise ensue.

In moulding the blocks, the thickness of the sides should be made of the same material throughout, and not made in two layers, as has been done, to economise the fine clay by placing a thin layer in front and using a coarser and inferior material on the back; the unequal contraction causes the two layers to separate.

Colour.—The colour varies with the temperature at which the clay is baked, and with the percentage of oxide of iron present. Colour may be imparted by giving the clay a wash of ochre paint before baking. This is inferior, soon wears, and should not be resorted to.

Two Colour Work.—Usually the blocks of terra-cotta are of one tint, but of late years Messrs. Doulton have perfected a process, by carefully selecting the earth, in which blocks, each of two colours, may be produced.

Fixing.—Terra-cotta blocks, when built in walls or anywhere to withstand pressure, have their voids filled up with ordinary Portland cement concrete; this usually causes discoloration due to the cement concrete working through. A filling composed of Portland cement and ground terra-cotta is more effective. The voids are left hollow in floors or any position where lightness is desirable.

Moulded work in terra-cotta, owing to the unequal shrinkage in drying, often becomes slightly twisted, which in buildings with a long run of cornice or string mouldings has a bad effect. This is often corrected by chiselling parts of the face; but it should not be allowed, as, if the vitrified surface skin be destroyed, the remainder will rapidly disintegrate under the influence of the weather.

The dimensions of the blocks are usually some multiple of brick dimensions, in order to bond with the brick backing.

Terra-cotta is most suitable for decorated panels, statuary, and work which would have to be carved if in stone, especially where these have to be reproduced several times.

STONEWARE.

Stoneware is prepared from clays of the Lias formation, consisting of silica and alumina, with a small percentage of iron, calcium, etc.

The clay is prepared in a similar manner to the brick-earth, usually being mixed with a proportion of ground stoneware or sand to avoid excessive contraction in burning.

The articles are moulded by various processes, and burnt in a domed kiln; the material is practically non-absorbent, but to ensure this the articles are glazed.

The glazing is performed by adding sodium chloride when in the kiln, which is volatilised by the heat, and in the form of a vapour is decomposed by the silicates of

alumina, with which it combines to form a glass, the chlorine passing off from the kiln.

The sodium chloride in the form of a vapour penetrates into all the pores of the stoneware, completely covering the surface with a coating of glass.

This material is chiefly used for such articles as drain and sewer pipes, damp-proof courses, or any position where a damp-resisting material is required. These are burnt in kilns at a very high temperature, and when finished are thoroughly vitrified throughout their whole thickness.

CHAPTER XIV.

STONES.

Classification.—Stones are divisible into three chief classes :—(*a*) Igneous, (*b*) Aqueous, (*c*) Metamorphic.

(*a*) *Igneous* rocks are of volcanic origin, having been formerly in a state of fusion, and include the granites, traps, and syenites.

(*b*) *Aqueous* rocks are those which have been deposited or formed in water or air, and include most of the limestones and sandstones in use for building purposes.

(*c*) *Metamorphic* are rocks of either of the above divisions which in many cases have been subjected to great heat, pressure, or both, sufficient to cause alteration in form, and may be simply a rearrangement of the particles as in clay slate ; a crystallization of the constituents producing rocks such as the marbles ; or the addition of new substances from solution in water percolating through rocks and producing new crystalline minerals such as the dolomites.

Stones may be further divided for building purposes into (1) sandstones, or those in which silica constitutes the base ; (2) limestones, in which carbonate of lime forms the base ; (3) slates ; and (4) granites.

Stones are either stratified or granular in structure. The stratified are those sedimentary rocks formed by successive deposits of the materials of which they are composed. The granular are those that have been formed by volcanic agency, or those sedimentary rocks whose original

structure has been altered by oscillations of the earth's surface and the action of fire or hot water.

The stratification in good specimens should not be visible to the naked eye, unless through the difference of colour; the grains should also be uniform in size. Such stones are useful for pavings, landings, etc., as they may readily be split along their planes of stratification, called in this case planes of cleavage.

Characteristics of Building Stones.—The salient characteristics of stones will be treated under the following heads: general structure, fineness of grain, compactness, porosity and absorption, weight, appearance, seasoning, natural bed and weathering.

General Structure.—Sandstones consist of grains of sand cemented together by one or more of the following: silicic acid (H_2SiO_3), carbonate of lime, carbonate of magnesia, peroxide of iron and clay.

Limestones usually consist of crystallized grains of carbonate of lime, joined together by a cement of the same material, and when these are capable of taking a polish are termed marbles; or, as in the oolite, of a number of grains, which are formed of calcareous matter deposited about a nucleus, the latter being usually small shells.

Marbles consist of a crystalline granular aggregate of calcite, white when pure and having the texture of loaf sugar, but passing into various colours according to the nature of the impurities. It occurs in beds among the schists, and is no doubt a limestone, formed either by chemical precipitation or by organic agency, which has been thoroughly metamorphosed by heat and pressure into its thoroughly crystalline character. Some of the fossiliferous limestones through which the Christiana granite rises have been changed into crystalline marble, but their original corals and shells have not been wholly effaced.

Dolomites are stones in which the chief constituents are

carbonates of lime and magnesia in nearly equal proportions. These are compact, crystalline, and oolitic in structure, and are superior to ordinary limestone.

The consolidation of these materials into solid rock has been accomplished by some or all of the following causes:—Pressure of overlying water or rock; partial solution or redeposition; and heat, either dry or moist.

Freestones are granular in structure, with no planes of cleavage, and therefore no tendency to split in any direction, and for that reason are useful for carved work.

Fineness of Grain.—Fine-grained stones are in great demand for carved or moulded work, as it is possible from these to obtain much finer arrises than from the coarser grained varieties. Such stones depend for their durability upon the extent of the crystallization of the particles, and the quality of the cementing material; but if the particles are amorphous and of an earthy appearance, they are bad, and will be readily disintegrated by any of the destructive agents.

Compactness.—Stones also depend for durability to a large extent on the compactness of the particles or density of the stone. For this reason the best building stones are those of the older formations found at a great depth, and having been subjected to the enormous pressure of the earth above. These stones are often found near the surface, due to alterations of the earth's crust from internal causes, such as volcanic eruptions, earthquakes, etc., or to denudations from external changes due to wind, running water, glaciers, etc., which wear away the upper crust of the earth, and expose the rocks of the older formations.

Porosity and Absorption.—All stones are porous, but some to such an extent as to render them unfit for building purposes, especially for structures in exposed situations, although the constituents and cementing material may be of a durable character.

Porous stones may be destroyed in one of two ways, or by both ways combined:—(*a*) by decomposition, (*b*) by disintegration.

Porous stones absorb much rain-water, especially when the faces of the buildings are exposed to the prevailing winds.

(*a*) Rain-water in its descent takes up some of the acids present in the air; these acids, chiefly sulphuretted hydrogen, hydrochloric acid, and sulphurous acid, exist in appreciable quantities in large and manufacturing towns. The rain lodges on the surfaces of the stones into which it soaks, being often driven in by the wind; the acids combine with the constituents of the stones, dissolve them, and cause the stones to crumble.

(*b*) In winter time, the water thus absorbed by the stone freezes, expands, disintegrating the particles and detaching portions of the surface. The adhesion of the particles in some stones is sufficient for a time to resist the expansive force of water when frozen; but even these give way in time to the action of successive frosts, especially when, added to this force, the stones are subjected to the effects of acids.

Stones should be tested for porosity by soaking samples in water, and noticing the amount they absorb.

Sandstones should not after twenty-four hours' immersion absorb more than 10 per cent. of their volume of water; limestones not more than 17 per cent.; granites not more than 1 per cent.

Weight of Stones.—The weight of stones should be taken into account, and they should be selected to suit the work to be executed. Heavy stones are required for buttresses, retaining walls, and marine structures, while for vaulting and similar work light stones are preferable. Weight is also an indication of the density, and therefore the porosity, of a stone.

Appearance.—In the choice of a stone for a building the colour is a good guide as to durability. Highly-coloured

stones are often preferred for their architectural effect, frequently at the expense of their durability. The red and brown shades of colour in all the sedimentary rocks are due to oxide of iron, which, if present in large quantities, is apt to disfigure the face of the stone by rust stains, and also leads to rapid disintegration; therefore, the lighter shades of any particular stone should be preferred to the darker tints. There should be no clayholes, bands, or spots of colour whatever, but the stone should be uniform in colour and in structure.

Seasoning.—All stones when freshly quarried contain a quantity of moisture known as quarry sap, which renders the stone soft and makes it easier to cut; therefore all work should be placed upon the stone as soon as convenient after quarrying.

Stones gain considerably in hardness by being seasoned.

Stones when once worked to a finished surface should not after have their dressed faces disturbed, as is often done on the cleaning down of a building, but should be when bedded covered with a wash of plaster of Paris and lime in about equal proportions, which latter can be easily washed off, and with it all the dirt and stains incident to building work, as the quarry sap when drying out leaves a hard crystalline skin on the face which will weather considerably better than any fresh face formed after the removal of the original worked surface. This applies with especial force to limestones.

It is important that the sap should be expelled before the stone is placed in a building, because when fixed it cannot dry out so quickly, thereby making it subject to disintegration by frost, easier for acids to act upon it, and being in a soft condition it is liable to break should any great weight be placed upon it.

Stones should therefore be left, after quarrying, to season for a considerable time, which is best accomplished by

leaving them in the open air, in order that they may be freely acted upon by the sun and wind. They are often placed under cover in a shed with no walls to allow a free access of air and to protect them from rain.

Natural Bed.—The natural bed in a stone is that surface on which the material was originally deposited, but is not necessarily horizontal as it rests in the quarry, the strata being often inclined and even upright, due to the beds having become folded and disturbed by volcanic and other agencies.

The purpose for which a stone is used determines the position of the natural bed, as this has an important effect upon its durability. Stones must be arranged so as to obtain—first, the maximum strength to resist crushing; and secondly, to offer the greatest resistance to disintegration by frost. This is done in the following manner:—(1) By placing the stone so that its laminæ are at right angles to the pressure, because the stone is much stronger for weight-carrying purposes when in that position than when the pressure is applied to the end grain of the stone; (2) if the laminæ of the stone be placed parallel to the face of the building, they will scale off successively from the effects of each succeeding frost, every lamina that peels off exposing a fresh face. The stones must therefore be placed with the edges of their laminæ at right angles to the face of the wall.

In walling, such as ashlar work, the laminæ are placed horizontally.

In strings and cornices, with undercut mouldings, the laminæ should be placed vertically, as if placed horizontally the laminæ would be likely to scale off. This principle cannot be carried out in the quoin stones of cornices and strings; if it were so bedded, the whole projection on the return face would after a few years have crumbled away. Such stones must be specially selected and be without any

apparent stratification, and laid on their natural bed. Cornices bedded with their laminæ vertically should be covered with lead, as water is readily conducted between the layers.

The laminæ in arches should be placed parallel to the centre line of the voussoirs, and at right angles to the face of the arch.

In good qualities of stratified stone the beds are not easily discernible, and require a practised eye to determine their direction. They may be easily detected in some stones by thin bands of a greenish or blackish colour of vegetable origin. The beds may often be determined by pouring a little clean water on the stone and noticing the direction it takes in descending. If the stone be examined through a powerful magnifying glass, the particles of which the stone is formed will sometimes be observed to be on their wide flat surfaces, and these flat surfaces are usually parallel to the bed of the stone; the planes of the minute flakes of mica occuring in most sandstones will be observed to lie in one general direction and indicates the natural bed.

Weathering.—The weathering of a stone is the extent to which its face will resist the action of the weather.

It will be noticed that those faces exposed to the prevailing wet winds (south-west in England), and those that get most saturated with rain, are the faces that show the signs of decay to the greatest extent, also shady parts, such as the underside of cornices, etc., that are at no time exposed to the sunlight, and which never get the moisture dried out of them, being consequently left to the rain with all its attendant defects.

The best way to determine the weathering qualities of a stone is to inspect buildings in the neighbourhood of the quarry that have been built with the stone in question, and also any faces of the quarry that have not been used

for a great length of time, and observe how they have weathered. If the stone be required for a building in a large town, this will not be sufficient data to judge of its weathering qualities, but a chemical test as hereafter described will be necessary.

Constituents of Stones.—In order to understand the chemical action of the atmosphere upon stones, a knowledge of the constituents of stones is indispensable.

The composition of the principal classes of stones used for building work is given in the following order below :—Granite, sandstones, limestones, slates.

Granite.—Typical granite is composed of quartz, felspar, and mica; the latter is frequently present in but very small quantities, with occasionally another mineral (hornblende).

Syenite.—Typical syenite is composed of felspar and hornblende.

Hornblendic Granite.—Those rocks containing the four minerals—quartz, mica, felspar, and hornblende—are termed hornblendic granite.

Basalt is a compact black rock, consisting chiefly of felspar, augite, olivine, magnetite, and titaniferous iron embedded in glass or crystallites.

Sandstones are composed of grains of silica cemented together by carbonate of lime or by silicic acid. Nearly all sandstones contain oxide of iron, to the presence of which they owe their colour. Besides these, sandstones often contain mica and clayey matter.

The stone may consist of grains of sand cemented together by lime or other material; the durability of the stone here depends on the quality of the cement, as the sand is indestructible; or, secondly, it may consist of particles of carbonate of lime or other substances joined together by a siliceous cement, in which case the grains are likely to decay, leaving only the cement, resulting in

a porous stone. The most durable sandstones are those formed of grains of silica, cemented together by silicic acid, with but a small quantity of other matters, such as the Craigleith, which contains about 98 per cent. of silica and only 2 per cent. of impurities.

Limestones consist chiefly of carbonate of lime, with small portions of silica, carbonate of magnesia, iron and clay, and are stratified or oolitic in structure.

Stones consisting of carbonate of lime and carbonate of magnesia in nearly equal proportions are known as dolomites or magnesian limestones. Where these two compounds exist in stones in a crystalline condition the stone is very durable.

Limestone also exists as gypsum or sulphate of lime, in a crystalline condition as alabaster, and is burned largely for plaster.

Slates are obtained from the Devonian, Silurian and Cambrian strata. It is a compact, fine-grained argillaceous rock that has been subjected to enormous pressure, and also to a shearing action which has caused planes of cleavage, independent of the original beds, often crossing them at a great angle. It is on these planes of slaty cleavage, as they are called, that the value of slates depends, as this enables them to be split with facility into thin laminæ, and thus form a light covering. They are composed chiefly of silica and alumina.

They vary in colour from purple to green, and are used in all parts of the kingdom for roofing purposes.

Characteristics.—A good roofing slate should be uniform in colour and free from patches, compact and sonorous, incapable of absorbing or retaining much water, hard and rough to the touch; those which feel smoth and greasy, or are purple in colour, being usually inferior for roofing purposes.

Tests.—A common test for roofing slates is to place one

on edge to half its depth in water for twelve hours. If the water approaches to top of the slate it should be rejected; if it does not rise beyond $\frac{1}{8}$th of an inch, it may be considered as practically non-absorbent. Another method is to weigh a well-dried slate, and after soaking for twelve hours in water to weigh it again; the difference in weight will show the quanity absorbed.

A good slate after twelve hours' soaking should not have absorbed more than $\frac{1}{200}$th part of its weight.

Chemical Composition.—The following is the chemical composition of the principal constituents of stones:—

Quartz is silicon oxide (SiO_2); it is practically indestructible.

Felspar is a silicate of alumina, with silicates of soda, potash or lime, $(Na,K)_2O.Al_2O_3.6SiO_2$. The K may be replaced by equivalent quantities of Ca, Mg, or Fe (ous). It often contains small quantities of oxide of iron, on which ingredient the colour of red granites depends. If it contains a large proportion of lime, soda, or potash, it will be liable to decay.

Mica is found in thin, hard, transparent plates or laminæ which readily split; it consists chiefly of silicate of alumina with potash, the formula $K_2HAl_3(SiO_4)3$. It imparts the glistening appearance to granite, is readily decomposed, and in large quantities is a source of weakness.

Hornblende is a silicate of lime and magnesia. These two constituents being in varying proportions, $5(Mg,Ca)O.6SiO_2$, it is very heavy and of a black or green colour.

Silicic Acid.—$(H_2O)x(SiO_2)y$ forms the best cementing material for all sandstones.

Augite is a similar substance to hornblende, $(Mg,Ca)SiO_3$.

Carbonate of Lime.—The basis of all limestones, $CaCO_3$.

Carbonate of Magnesia.—$MgCO_3$ exists in numbers of limestones. When above a certain proportion of magnesium

the stone is called a dolomite ; and its formula is represented by $(Ca,Mg)CO_3$.

Gypsum is a hydrated sulphate of lime, $CaSO_4.2H_2O$.

Alumina.—Al_2O_3 is an oxide of the metal aluminium; combined with silica it forms the basis of clay.

Kaolin.—$Al_2O_3.2SiO_2.2H_2O$ is a pure white clay derived from the decomposition of felspar, which has been acted upon by water containing carbonic acid, which latter dissolves the lime, potash, and soda, leaving the silica, alumina, and water.

Chemical Tests.—Immerse a few chippings of the stone in a 5 per cent. solution of dilute sulphuric and hydrochloric acids for three days. When taken out and dried the surface grains should still be firm and the angles sharp. Loose sand about the surface would indicate a speedy dissolution in a town atmosphere.

A few drops of the pure acids dropped on to a sandstone would, if effervescence took place, indicate lime as a constituent, probably as the cementing material. Such a stone would not weather well.

The following is a list of the stones most largely used :—

LIMESTONES.

Ancaster.—An oolite quarried in Lincolnshire. Composed of :—

Carbonate of Lime	93·59
Carbonate of Magnesia	2·9
Iron and Alumina	·8
Water and loss	2·71

It has a specific gravity of 2·182. The colour varies from a white to yellow and pink. Most of the Lincolnshire churches are built of this stone; it is used for local building work generally, in London and the Midland counties for dressings to doorways, windows, etc.

Box Ground, *Corsham* and *Coombe Down* are varieties of the Bath oolite. Composed of:—

Carbonate of Lime	94·52
Carbonate of Magnesia	2·5
Iron and Alumina	1·2
Water and loss	1·78

It has a specific gravity of 1·839. Varies from a light cream to a yellow colour. Of the three the Box Ground is the best weathering stone. It is largely used for dressings, carved and moulded work,

Bath stone to endure must be kept dry and be laid on its natural bed.

Fine-grained Corsham is good for interior work and external work well above the ground level. In the six months of winter the stone is dug and stacked under ground, and is then brought to the surface and is seasoned for a period such as six months before being used.

Box Ground is good in all situations, but if used for walls must be at least 18 inches thick to prevent damp passing through. It is quarried in the severest weather and withstands all injury from the weather. Exposure causes the quarry sap to evaporate, and the stone hardens and therefore gets more difficult to work.

Portland.—An oolite from the Isle of Portland. Composition as follows:—

Silica	1·2
Carbonate of Lime	95·16
Carbonate of Magnesia	1·2
Iron and Alumina	·5
Water and loss	1·94

It has a specific gravity of 2·145. The colour varies from a white to a light brown, the latter being considered the better. There are four beds of Portland, the true Roach,

Whitbed, bastard Roach, and Basebed, the Roach and Whitbed being the best. Portland stone is used for building work generally, and is found to weather better than all other limestones for large towns.

There are three districts in Portland—Wakeham, Minesthay, and Weston—which supply stone in marketable quantities. Their properties seem generally to vary considerably. The first is good to withstand atmospheres charged with sulphuretted hydrogen, such as Birmingham; the second lasts well in sea-coast districts, such as Eastbourne and Portsmouth, and stands well in London. Stone from the third district is good in moist and forest atmospheres, and especially north and west of England and Ireland; for important buildings it would undoubtedly be wise to consult the quarry owner in the selection. Although it is safe to lay Portland stone on its natural bed, it is not so important as in Bath and other limestones.

Ham Hill is obtained from Somersetshire. Composition as follows:—

Silica	4·7
Carbonate of Lime	79·3
Carbonate of Magnesia	5·2
Iron and Alumina	8·3
Water and loss	2·5

Specific gravity 2·26. Colour, yellow and grey; the first is bright when first quarried, but tones down. Used for facings and dressings, weathers well.

Chilmark.—A brown oolite, obtained from Wiltshire. Composition as follows.

Silica	10·4
Carbonate of Lime	79·0
Carbonate of Magnesia	3·7
Iron and Alumina	2·0
Water and loss	4·2

Specific gravity 2·481. Light brown in colour. Very durable. Used for general building work, specially suitable for steps and paving, and much used for heavy engineering work.

Doulting Freestone.—An oolite of uniform texture obtained near Shepton Mallet, Somersetshire. Composition as follows:—

Carbonate of Lime	95·89
Carbonate of Magnesia	·11
Alumina	·79
Sesquioxide of Iron	·85
Silica	2·04
Water	·32

Specific gravity 2·45. It varies from a cream to a brownish yellow colour. It is very durable, and suitable for general building work.

Hopton Wood.—A fossil limestone quarried in Derbyshire, takes a good polish; used for ornamental paving, wall panels, and decorative purposes.

Little Casterton.—An open oolite quarried near Stamford; used locally for general building purposes.

Purbeck Marble.—From the upper oolite beds, quarried at Purbeck, in Dorsetshire. Mottled grey in colour, takes a fine polish; much used for internal church work, being suitable for slender columns and decorative work.

Caen.—A fine oolite quarried at Caen, in Normandy. It has been largely imported into England, but is a failure for external work, as it weathers very badly, but is much used for internal work for decorative purposes, being well adapted for carving.

Maningham.—A sandy limestone quarried near Boulogne in France, suitable for pavements. Is not largely used in England.

MAGNESIAN LIMESTONES.

Bolsover.—From Derbyshire. Composition as follows:—

Silica	3·6
Carbonate of Lime	51·1
Carbonate of Magnesia	40·2
Iron and Alumina	1·8
Water and loss	3·3

It has a specific gravity of 2·267. Light yellowish-brown colour. Good durable building stone, also for paving.

Mansfield Woodhouse.—Obtained from Nottinghamshire. Composition as follows:—

Silica	3·70
Carbonate of Lime	51·65
Carbonate of Magnesia	42·60
Water and loss	2·05

Specific gravity 2·33. Yellow colour. Much used for internal decorative work, does not stand well externally.

Huddlestone.—Quarried at Sherburn in Yorkshire. Composed as follows:—

Silica	2·53
Carbonate of Lime	54·19
Carbonate of Magnesia	41·37
Iron and Alumina	1·3
Water and loss	1·61

Specific gravity 2·14. Cream colour. Suitable for general building purposes.

Roche Abbey.—Quarried near Bawtry, Yorkshire. Composed as follows:—

Silica	·8
Carbonate of Lime	57·5
Carbonate of Magnesia	39·4
Iron and Alumina	·7
Water and loss	1·6

Specific gravity 2·14. Light cream colour. This stone is suitable and is much used for general building purposes, but is subject to discoloration.

Park Nook.—Quarried near South Milford, Yorkshire. Composed as follows:—

Carbonate of Lime	55·7
Carbonate of Magnesia	41·6
Iron and Alumina	·4
Water and loss	2·3

Has a specific gravity of 2·13. Cream colour. Moderately good building stone, much used locally.

SANDSTONES.

Craigleith.—Quarried near Edinburgh. Composed as follows:—

Silica	98·3
Carbonate of Lime	1·1
Iron and Alumina	·6

Specific gravity 2·232. Whitish-grey colour. Very hard and durable, good for ashlar and general building purposes. Specially suitable for landings, steps, etc. This quarry is nearly worked out.

Hailes.—The stones from these quarries, near Edinburgh, in the neighbourhood of Craigleith, are of three tints, white, pink, and bluish grey.

The white rock appears from its more complete secondary silicification to be the strongest and most compact in structure of the three varieties. The small percentage of iron and of the ferrous compounds points to a probability of greater immunity from discoloration and liability to rust stains than the blue rock; it is finer in grain, and on all

accounts to be preferred to the blue rock. The following gives the analysis of the white rock :—

Silica	96·52
Lime	·409
Sodium Oxide / Potassium Oxide	·27
Ferrous Oxide	·19
Ferric Oxide	·056
Alumina	2·78
Loss on ignition	·31
	100·535

The blue rock has the most marked lamination, and the cementitious matter is partly aluminous. The blue colour is due to fine lines of carbonaceous matter. The following is the analysis :—

Silica	92·23
Lime	·81
Magnesia	·19
Sodium Oxide / Potassium Oxide	·18
Ferrous Oxide	1·71
Ferric Oxide	·013
Alumina	2·93
Loss on ignition	1·73
	99·793

The pink is a variety having properties intermediate between the white and the blue. The following is the analysis :—

Silica	96·7
Lime	·36
Magnesia	trace
Sodium Oxide / Potassium Oxide	·13
Ferrous Oxide	·25
Ferric Oxide	1·46
Alumina	·84
Loss on ignition	·58
	100·32

Stone from this quarry has been used largely in Edinburgh and neighbourhood for the last two centuries, and has proved an excellent weathering stone for general building purposes. It is especially suitable for templates, steps, landings, and pavements, and can be obtained in very large blocks. The following test for transverse strength was made on this stone at the New Art Galleries, Kelvingrove, Glasgow. The steps tested were each 11 feet 6 inches long, having a 9-inch wall hold at each end. Three steps were built into walls having a clear span of 10 feet. They were then gradually loaded on top with steel joists till the load reached six tons. The deflection at centre of steps was $\frac{3}{8}$ths of an inch. The loading occupied a space of 4 feet in the centre of the steps. The intention was to load until they broke, but when the results were so satisfactory the steps were saved.

Bramley Fall.—Originally quarried near Leeds, but the name is now used to denote the coarse millstone grits of Yorkshire. Specific gravity 2·11. Light brown colour. Very durable and good for general building purposes. Specially suitable and much used for pavings, steps, girder beds, engine beds, etc.

Darley Dale. — Quarried near Bakewell, Derbyshire. Composed as follows:—

Silica	96·4
Carbonate of Lime	·36
Iron and Alumina	1·3
Water and loss	1·94

Specific gravity 2·62. Light brown colour. Good for general building purposes, and is largely used.

Professor J. Shipman, F.G.S., in his report upon the best building stones, says:—"The excellent quality of the stone from the Stancliffe Quarries, Darley Dale, is seen in the entrance lodge and gates of the park (to Stancliffe Hall),

which are built of it. The work presents a superbly clean and crisp appearance, the most delicate sculpturing and cornicing standing out as sharp and clear as if it had been chiselled the previous day. The stone is of a light drab or yellowish-white colour, inclining to a very pale greenish tint, but the colour of the stone is so subdued that it is almost white. There are no streaks or blotches of red about it, and its texture is very uniform throughout. When very closely examined it seemed to be a close-grained, finely micaceous grit, the mica occurring in only very minute silvery spangles.

"The rock is a thick-bedded grit, compact and very hard. It has been largely quarried, and is considered by the authorities to be a most valuable stone.

"St. George's Hall, Liverpool, is perhaps the finest example of a building in which this stone has been employed."

Heddon. — Quarried near Newcastle, Northumberland. Composed as follows:—

Silica	95·1
Carbonate of Lime	·8
Iron and Alumina	2·3
Water and loss	1·8

Specific gravity 2·29. Light brown colour. Durable stone, good for general building purposes.

Kenton. — Quarried near Newcastle, Northumberland. Composed as follows:—

Silica	93·1
Carbonate of Lime	2·0
Iron and Alumina	4·4
Water and loss...	·5

Specific gravity 2·24. Light brown colour. Good for general building purposes, particularly for fine and carved work.

Grinshill Freestone.—Quarried near Yorton, Shropshire. Composed as follows:—

Silica	95·46
Alumina	1·17
Peroxide of Iron	·87
Carbonate of Lime	·61
Carbonate of Magnesia	·69
Water	1·2

Specific gravity, 1·96. Yellowish-brown colour. A fine-grained soft sandstone, extensively used for facing and general building work.

Scotgate Ash.—Quarried at Pately Bridge, in Yorkshire. Specific gravity 2·45. Greyish-yellow in colour. It is fine-grained, hard, laminated sandstone, suitable for staircases, pavements, etc.

Howley Park.—Quarried at Morley, Yorkshire. Specific gravity 2·56. Light brown colour. A fine-grained homogeneous sandstone, durable, not hard, used for dressings, stairs, pavings, and general building work.

Robin Hood.—Quarried near Wakefield, Yorkshire. Greenish-grey colour. Durable, suitable for landings, staircases, etc.

Corsehill.—From Annan, in Dumfriesshire. Specific gravity 2·46. Dark red and bright pink in colour, contains about 95 per cent. of silica. Good weathering stone, suitable for carvings, dressings, and ashlar.

Magnesian Sandstones.

Red Mansfield.—Quarried near Mansfield, Nottingham. Composed as follows:—

Silica	49·4
Carbonate of Lime	26·5
Carbonate of Magnesia	16·1
Iron and Alumina	3·2
Water and loss	4·8

Specific gravity 2·33. Reddish-brown colour. Oolitic in structure, very durable. Suitable for general building work, carving, moulding, etc.

White Mansfield.—Quarried in the same district as Red Mansfield. Composed as follows :—

Silica	50·0
Carbonate of Lime	41·3
Carbonate of Magnesia	7·3
Water and loss...	1·4

Specific gravity 2·33. Whitish-brown colour. Similar in all respects to the red variety, but is not considered so durable.

GRANITES.

Igneous Rocks.—The igneous rocks as used for building purposes consist of granites and basalts, which are of a crystalline granular structure.

Quarrying and Working.—In Great Britain granite is chiefly obtained from Cornwall and Aberdeenshire. As the British quarries are insufficient to supply the demand a great quantity is imported from Guernsey, Norway, Sweden and Russia, but the working of the granite from all parts is chiefly carried on at Aberdeen.

The method of quarrying is as follows:—Blocks are detached by blasting, which are hauled from their position in the quarry by means of steel rope railways to the point at which they are worked. Blocks are roughly squared into suitable dimensions by nicking a line about the stone and sinking small holes about 1 foot apart, into which are inserted steel wedges and feathers. These are tapped with a hammer in succession, until the stress becoming too great the stone is rent through the plane bounded by the nicking. The stones are also roughly faced at the quarries with hammers, and fine-faced with hammers and chisels. Large surfaces are now more expeditiously faced with a surfacing machine. The block is placed in position, and a large

surfacing tool worked by pneumatic power is caused to strike the stone with a series of rapidly-delivered blows, the tool being guided by the hand. The surface is gradually worn to a uniform level. Pneumatic chisels are used also for lettering, carving, and moulded work. Granite is sawn into slabs by means of toothless steel blades, assisted by chilled cast-iron shot, the stones being divided at the rate of about 2 inches per hour. The stones for polishing are placed on a table and bedded in plaster of Paris. The surface is rubbed and polished by means of heavy circular iron rubbers rotating on vertical axes, the table having imparted to it a reciprocating horizontal motion, thus permitting of the entire surface being rubbed uniformly, chilled shot, carborundum, sludge, and putty powder being used as mediums to produce the polished surfaces. For moulded work, cast-iron slippers, the reverse of the mouldings are caused to work over the members to be polished, which are embedded in plaster to preserve the arrises and mitres. Circular work is turned and polished in lathes.

Classification. — Igneous crystalline rocks are usually classified as follows :—

(1) Acid rocks, with 65—80 per cent. of silica.
(2) Intermediate rocks, with 55—70 per cent. of silica.
(3) Basic rocks, with 45—60 per cent. of silica.
(4) Ultra-basic rocks, with 35—50 per cent. of silica.

Granites are included in Group I. Syenite proper, containing felspar and hornblende, but no free silica, belong to Group II. Basalts belong to Group III., whilst the rocks of Group IV. are too rare to be used for building purposes.

Stones comprised in the groups other than I. are often incorrectly termed granites.

Grey Aberdeen.—Quarried at several places in Aberdeenshire. Takes a high polish; suitable for columns and ornamental work, largely used for kerbs and sets.

Rubislaw.—One of the chief quarries is Rubislaw, near

Aberdeen. It is fine-grained, grey in colour, and can be obtained in blocks as large as 240 cubic feet. It takes a high polish, is extremely durable, and is largely used for constructional, monumental, and decorative purposes, and can be obtained in large quantities. The following is its composition, given by Professor Geikie :—

"This rock is a true granite. It contains white and black micas (muscovite and biotite), of which the latter is the more abundant, together with felspars and quartz.

"Of the felspars, microcline is the most prevalent, but plagioclase occurs in fair quantity. Fine needles of rutile are seen in the quartz. Other accessory ingredients sparingly present are zicron, apatite, and magnetite.

"This is one of the most durable kinds of granite."

Pink Aberdeen.—Various shades of this kind are quarried in Aberdeenshire. It answers the general description of the grey varieties.

A noted quarry is that of Corrennie, the stone from which is of a close-grained pink variety, and is largely used for constructional and decorative work.

Peterhead.—The stone from this quarry in Aberdeenshire is of a coarse red variety, and is largely used for constructional and decorative purposes. Many large polished columns have been executed in this material.

Cornish Granite.—Obtained in various parts of Cornwall. Grey in colour. Is largely used for engineering works, bridges, and similar constructions.

Guernsey Granite.—Quarried in Guernsey. Varies from reddish-brown to a grey-blue colour. It is a syenitic granite, containing felspar, quartz, hornblende, and a little mica, used chiefly for paving sets.

Swedish Granite—Victoria Grey.—This rock is quite a normal granitite, and belongs to the acid group, and contains orthoclase, biotite, and quartz. Along with these occur a little microcline and micropegmatite, apatite, and

zicron. The last-named is enclosed in the biotite, and is surrounded by black halos. Is used for decorative and monumental work.

Finland Granite.—This rock is a fine hornblende—granitite. It has a schistose aspect—a structure which is not seen under the microscope.

The chief mineral constituents are—hornblende, biotite, orthoclase, plagioclase, and quartz.

The accessory and minor ingredients are apatite, magnetite, zicron, and sphene—the last-named being fairly common. The hornblende is green, and the biotite is dark brown. Both occur in small crystals, usually associated, and often well-formed. The orthoclase is very fresh and abundant. Plagioclase is not very common. Quartz occurs in fair quantity. Epidote (a secondary mineral, or product of decomposition) is present.

It is a rock of the acid group, but more basic than the Victoria grey. Is used for decorative and monumental work.

Norway Granite. — A fine-grained granite quarried in Norway, extensively used for curbstone pitchings; it is preferred on account of the great lengths in which it can be obtained.

Swedish-Labradorite.—This is a rock of the intermediate group, and is not a true granite. It is a greyish green and very coarsely crystalline rock. To the naked eye it seems to consist chiefly of large felspars, showing some play of colours, with a subordinate proportion of dark mica and pyroxene.

Under the microscope the felspars prove to be the varieties known to mineralogists as anorthoclase or cryptoperthite (that is, mixtures of albite and orthoclase).

The other ingredients are dark greyish green augite with dillage-structure, deep brown biotite (mica), magnetite, and apatite, which appears in relatively large crystals. This rock belongs to the class of augite-syenites (known to geologists as laurvikites), which are well developed in

Southern Norway. (The rocks referred to are somewhat variable in composition, containing often zicron; occasionally olivine and nepheline, and less commonly quartz.)

Used for monumental and decorative work.

Swedish Bon-Accord.—This is a rock of the third or basic group, and is not a true granite.

This rock is an olivine-gabbro. Its constituent minerals are plagioclase, felspar, augite (diallage), and olivine, with a small proportion of black mica and magnetite. This plagioclase occurs in fairly well-formed crystals which are occasionally enclosed in the augite—thus showing a tendency to what is known as the ophitic structure so commonly seen in the rock called diabase. The olivine is very fresh and rather abundant. The black mica (biotite) mostly occurs in the form of scales around the magnetite.

Gabbros of this character occur at Elfdalen, in Sweden.

Used for monumental and decorative work.

Granite does not successfully resist the action of fire or acids.

Porphyritic Granite—Shap Fell.—The stone from this Westmoreland quarry is of a reddish brown tint, and contains large pinkish crystals of felspar, takes a high polish, and is largely used for decorative work.

Weight, Strength and Absorption.—The table on the following page gives the weight, strength and absorption of the stones in most general use.

Preservation of Stone.—Of late years, a solution known as Fluate, and prepared by the Bath Stone Firms has been introduced and extensively used to harden and preserve limestones in new work from decay, and also it is useful in preventing the decay in old work going farther. It does not materially alter the colour nor apparent texture of the stone to which it is applied, but it hardens the face and renders the stone more durable. The work is first cleaned, and then the fluate is laid on the face with a brush.

Browning's Patent Colourless Preservation Solution (The Indestructible Paint Co.), which is invisible when applied, is good for preserving sandstones and granites. It has

—	Weight per cubic feet in lbs.	Absorption in percentage of its dry weight.	Crushing load per square foot in tons.
LIMESTONES—			
Ancaster Freestone	140·4	6·27	184·0
Box Ground	127·9	7·49	97·5
Coombe Down...	128·6	5·80	117·7
Corsham Down	129·0	11·06	94·5
Doulting Freestone	125·0	11·05	103·9
Ham Hill	136·0	—	166·3
Monks Park	136·7	7·74	139·6
Portland, Whitbed	132·3	7·51	204·7
DOLOMITES—			
Red Mansfield	143·2	4·58	591·9
White Mansfield	140·1	5·01	461·7
Yellow Magnesium Limestone	145·4	4·62	577·4
SANDSTONES—			
Blue Hailes	143·2	4·70	459·7
Bramley Fall	132·2	3·70	238·4
Corsehill	130·4	7·94	444·9
Cragleith	138·6	3·61	861·9
Dean Forest	151·4	2·71	530·0
Darley Top	139·0	3·40	516·7
Howley Park	140·3	4·90	466·7
Robin Hood	144·6	3·90	574·0
White Grinshill	122·5	7·80	209·3
White Hailes	143·8	3·71	662·0
GRANITES—			
Aberdeen Corennie (Pink) ...	159·1	0·42	1318·3
,, Peterhead (Red) ...	158·5	0·29	1207·7
,, Rubislaw	163·7	—	1098·8
Cornish Grey	161·7	—	955·9

been used on Cleopatra's Needle. The Silicate Paint Co., Charlton, supply a solution which is good for bricks and porous materials, but is visible.

CHAPTER XV.

EXCAVATORS', BRICKLAYERS' AND MASONS' QUANTITIES AND MEMORANDA.

Necessary knowledge.—To be able successfully to take off quantities from drawings, and prepare estimates preparatory to pricing, three things are necessary—first, a thorough knowledge of arithmetic and mensuration; secondly, a sound knowledge of the details of building construction; thirdly, practical experience in the application of the two foregoing qualifications, to take off the measurements and state them in the manner usually adopted and understood.

The detailed dimensions are first of all "*taken off*" the drawing, and written down in columns, in the order of the length, breadth and depth, with an abbreviated description of the work to which the dimensions refer. When this has been done the next operation is "*squaring the dimensions,*" to obtain either the cubic or superficial measurements resulting from each set of dimensions. These results are collected together in the "*abstract*" for each trade; the total "*collections*" in each abstract are then placed in their proper order in a "bill of quantities"; the bill is ruled so that a price and a total may be placed against each item; the sum of all the totals will give the total proposed cost of all the work mentioned and described in the bill of quantities. This is termed the "*estimate.*"

The following are some general notes relating to the measurement of the various items of labour and material, under the proper trade headings.

EXCAVATORS' WORK.

General Digging, at per yard cube. Beyond 6 feet deep, keep separate and divide into stages of 6 feet each; wheeling over 20 yards keep separate, and divide into runs of 20 yards each; basketing out, keep separate, if no concrete take digging 6 inches wider than base of footings; describe if dig and cart away; dig, wheel, and spread, or if dig and part fill in and ram. In trenches the space occupied by the concrete and wall is dig and cart or dig, wheel, and spread. The remaining space is dig, fill in, and ram.

Concrete at per yard cube generally; if under 12 inches deep at per yard superficial. State proportions of materials to be used, if in lime or cement, &c.

Wells, at per yard cube, stating diameter, depth, distance to be removed and description of soil.

Surface Digging, at per yard superficial, if 12 inches deep or under.

Spread and Level, at per yard superficial, with description of average depth.

Hard brick rubbish, at per yard superficial, if 12 inches deep or under; above, at per yard cube.

Clay Puddle at per yard super, describing thickness.

Shoring, Strutting, and Planking at per foot super, to *trenches* under 6 feet wide at per foot run.

Drains at per foot run, to include digging, laying, jointing, concreting, filling, and ramming. Take a running dimension over all pipes and connections. When the latter are taken they are charged as extra only upon the cost of this item. State size of pipe, with description, how jointed and enclosed, and the average depth of the trench.

Lengths of drain upon which there is any additional labour should be kept separate and so described, such as "deep digging," "tunnelling," "strutting to trench," &c.

Bends, Junctions, Traps and Gulleys are numbered, and having been measured in the length of the drain are described as "extra only" upon the cost of the drain. *Manholes* are numbered and described.

Piles are numbered. State size and description of timber and length to be driven.

Number the rings, shoes, pointing, and cutting off heads when driven; state weight of ironwork.

Memoranda.—The following is the ratio of the increase in bulk of the undermentioned earths when excavated:—

Earth and clay	about	$\frac{1}{4}$
Sand and gravel	"	$\frac{1}{12}$
Chalk	"	$\frac{1}{3}$ to $\frac{1}{2}$
Rock	"	$\frac{1}{2}$ to $\frac{5}{6}$

In the mixing of concrete the final bulk is about $\frac{2}{3}$ of the volume of dry materials before mixing; for instance, a cubic yard of concrete *in situ* requires about $1\frac{1}{2}$ cubic yards of cement, gravel and sand.

BRICKLAYERS' WORK.

Brickwork, where used in large masses as for engineering works, is sometimes measured per foot cube. The usual London method is as below:—

The following is measured superficially:

Brickwork in mortar, at per rod of 272 superficial feet, $1\frac{1}{2}$ bricks thick, all thicknesses to be reduced to this standard.

All half-brick walls are measured similarly but priced separately.

Brickwork in cement, measured as above, but usually included in the brickwork in mortar, and described again separately as "*Extra only in cement.*"

Keep all above 50 feet 0 inches from the ground separate, also all built in small pieces.

Facings are measured at per foot superficial, as "*extra only*" upon the cost of the general brickwork, allow 3 inches below the ground and 3 inches at junction of roof with gable wall.

Fair face and point, at per yard superficial, where the same kind of bricks are used in face and body of wall.

Fair and rough cutting all over 6 inches wide at per foot superficial.

Damp course at per foot superficial.

Arches in Walls in lime mortar are measured in with the ordinary brickwork. Rough arches in cement, axed or gauged arches, are described and charged as "*extra only*" upon common brickwork, all extra necessary labour and material above those required in the common brickwork are charged for in all arches, such as fair or rough cutting, turning pieces, &c.

Trimmer Arches and Vaulting at per foot super, describing and stating thickness.

The following work is all measured by the superficial yard: Brick-paving, brick-nogging, rough rendering, cement floated face, cement or tar-paving, asphalte-paving, and tiling on brick.

The following is measured per foot run:—

Fair and rough cutting, if under 6 inches wide.

Birdsmouth, squint quoin, cutting and pinning.

Chase for pipes, cutting, toothing, splays, chamfers.

Cement fillet, lime and hair filleting, joints of groined arches, rake and point flashings.

All the following to be numbered, with a proper description:—

Mitres and stopped ends to cornices, strings, &c., bedding and pointing door and window frames; flues, parge, and core, stating average length; ends of sills cut and pinned,

holes cut for pipes, coppers, and setting; all stoves and setting; chimney pieces and fixing; brick seatings to w.c. traps, trimmer arches levelled up for hearths, rendering chimney backs in cement, air bricks and fixing.

Memoranda.—To reduce cubic feet of brickwork to rods, $1\frac{1}{2}$ bricks thick, deduct $\frac{1}{9}$th, and divide by 272.

Facings require about 7 bricks per foot superficial, a rod of brickwork with a $\frac{3}{8}$ inch joint requires 4,356 bricks and $3\frac{1}{30}$ cubic yards of mortar. Allowing for waste and consolidation this will mean 4,500 bricks, $1\frac{1}{2}$ yards of chalk lime, and 3 yards of sand, or 4,500 bricks, 1 yard of stone lime, and $3\frac{1}{2}$ yards of sand, or 36 bushels of cement and 36 of sand to bricks as before, or 30 bushels of blue lias lime to 60 bushels of sand. A ton of Portland cement is 11 sacks. There are 21·09 striked bushels to 1 yard, 30 bushels of lump lime to 1 ton of quicklime, 26·6 bushels of ground lime to 1 ton of quicklime.

In the mixing of lime and cement mortars of the usual proportions the final volume may be taken as about $\frac{2}{3}$rds of the volume of the dry materials before mixing, as may be deduced from the quantities for $3\frac{1}{30}$ cubic yards of mortar required for a rod of brickwork.

A striked bushel = 1·28 cubic feet, therefore a cubic yard = 21·09 striked bushels.

MASONS' WORK.

Take all stone at per foot cube including hoisting and setting. If the hoisting is over 40 feet in height, take an extra to, and divide into heights of 20 feet, as 40 feet to 60 feet, 60 feet to 80 feet, &c.

All labours to be taken separately and to be measured at per foot super. The final labours include all preparatory labours:—

Half sawing or half plain.—This labour is taken to all

faces upon which no other labour is taken, such as the back of ashlar work, the back of a cornice, &c.

Half plain work.—This labour is taken to beds and joints; each of the two worked surfaces to each joint is paid for as half plain work.

Plain work.—This labour is taken to all exposed plain surfaces, upon which no further labour is placed.

Sunk beds and joints.—Taken in all cases where the face of the bed or joint is sunk below the general face.

Sunk face.—In all cases where the face of the work is sunk back or recessed, and the surface is equal to plain work.

Moulded work.—All mouldings where the girth exceeds 6 inches.

Circular face; Circular sunk face; Circular moulded face.—When the work is circular on plan as well as circular on face, the work is described as *circular circular.*

Pavings.—Measured with description.

Landings; also treads and risers, hearths, shelves, large templates, and cover-stones over girders.

The following labours are measured at per foot run :—

Moulded work, under 6 inches girth, rebate and chamfer, joggle joint, groove, throating.

The following at per foot run will include both labour and material :—

Curbs, steps, window-sills, thresholds, not exceeding 18 in. × 6 in. in section.

The following items are numbered :—

Stopped ends and mitres to mouldings, splays, chamfers, &c., with proper description; mortices, dowels, lead plugs, circular perforations, holes for pipes, cramps for copings, sinks, gully stones, chimney pieces, small templates, corbels.

STONE WALLING.

Rubble work is measured at per foot cube, to walls 2 feet or above in thickness. Walls less than 2 feet in

thickness are kept separately, and their thicknesses stated.

The extra labours on face work should be taken separately.

WEIGHTS OF VARIOUS BUILDING MATERIALS.

Materials.	Specific Gravity.	Weight of a cubic foot in lbs.
Water, pure, at 39·4° Fahr. ...	1·0	62·425
,, sea, ordinary	1·026	64·05
Clay	1·92	120
Sand	1·546	96·35
Gravel	1·8	112·6
Chalk	1·87—2·78	117—174
Shale	2·6	162
Marl	1·6 — 1·9	100—119
Slate	2·8 — 2·9	175—181
Limestone	2·7 — 2·8	169—175
Sandstone	2·3	144
Granite	2·63—2·76	164—172
Gypsum	2·3	143·6
Zinc, sheet	7·190	448·1
,, cast	6·861	427·6
Tin	7·291	454·4
Copper, sheet	8·785	547·5
,, cast	8·601	536·4
Bronze	8·4	524
Brass	8·393	523·1
Lead	11·352	707·5
Cast Iron	7·2	450
Wrought Iron	7·6	480
Steel	7·8	490
Fir	·48	30
Pitch Pine	·631	39·43
Oak, European	·69 — ·99	43—62
,, American	·87	54
Elm	·588	36·65
Mahogany, Honduras	·560	34·9
,, Cuba	·85	53
Teak, Indian	·66 — ·88	41—55
,, African	·91	61
Glass, Crown	2·5	156
,, Flint	3·0	187
,, Plate	2·7	169

EXAMINATION QUESTIONS.

FOUNDATIONS.
Questions 1—12

BRICKWORK.
Questions 13—28

DRAINS.
Questions 29—48

MASONRY.
Questions 49—68

WALLS.
Questions 69—80

ARCHES.
Questions 81—89

FLUES, FIREPLACES, TALL CHIMNEYS, ETC.
Questions 90—100

LIMES AND CEMENTS.
Questions 101—116

CONCRETE.
Questions 117—120

BRICKS, TERRA COTTA AND STONEWARE.
Questions 121—131

STONES.
Questions 132—151

QUANTITIES AND ESTIMATING.
Questions 152—160

The following questions are taken or adapted from those set by the undermentioned authorities.

ABBREVIATIONS.

B.E., A.B. = Board of Education, Advanced Building Construction.
B.E., H.B. = Board of Education, Honours Building Construction.
R.I.B.A. = Royal Institute of British Architects.
W.O.S. = War Office Surveyors Examination.
M.E. = Institute of Municipal Engineers Examination.
C.G. = City Guilds Examinations.

EXAMINATION QUESTIONS.

FOUNDATIONS.

1. Sketch and dimension the shoring you would adopt in excavating a trench 12 feet deep and 6 feet wide in loose material. (W.O.S., 1900.)
2. The external angle of a three-storeyed house on a clay soil has settled, cracking both the return walls severely from top to bottom. Illustrate by sketches how you would shore the building to render it safe until reconstruction can be undertaken. (R.I.B.A., 1900.)
3. Why is it advisable to carry the masonry or brickwork of a building well below the surface of the ground, independently of sufficiency of bearing? Name what you think should be a minimum depth; give the circumstances under which you would not insist upon it. (B.E., A.B., 1901.)
4. Sketch the nature of the foundations you would put under a retaining wall having a base 10 feet wide, when the substratum is (*a*) blue clay, (*b*) running sand, (*c*) compact sand and gravel. (W.O.S., 1898.)
5. Sketch three different kinds of iron pile points for carrying an iron superstructure—say a pier—and state the conditions under which each would be used. (W.O.S., 1898.)
6. Give descriptions of the materials you would employ in dealing with a foundation in running sand, and the tests you would use to ascertain the nature of the foundation, and how you would decide the depth at which you would start your foundation. (R.I.B.A., 1900.)
7. Sketch the section through the front wall of the basement of a large warehouse of five storeys, the basement floor being 15 feet below the ground floor, the former floor to carry heavy merchandise, and the latter heavy cart traffic. The substratum is gravel. (W.O.S., 1898.)
8. The foundations of a stone wall have to be dug in running soil 10 feet deep. Show what timbering you consider necessary to prevent the ground from falling in, and name the different parts. (C.G., 1903.)

9. A new building, with a basement extending 20 feet deep below the ground, is to be erected on a site adjoining a passage 5 feet wide. On the other side is an old building 4 storeys high with a basement only 7 feet deep. The soil is unreliable made ground, and the old building has rough chalk on stone footings without concrete. What precautions would you take to secure the safety of the old building, temporarily and permanently? Illustrate your answer with sketches about $\frac{1}{4}$-inch scale. (R.I.B.A., 1900.)

10. A road has to be cut through a bank of running sand. Give a list of materials you would use in building the retaining walls, and the precautions you would take to prevent the walls giving way. (R.I.B.A., 1902.)

11. (*a*) Sketch to the scale of $\frac{1}{8}$ the head and point of a 12-in. by 12-in. timber pile prepared for driving. (*b*) What do you know of the pressure between the base of the monkey and the head of the pile after impact? (*c*) If a monkey weighing 8 cwt. falls 7 feet to the head of a pile and drives the pile 1 foot, what is the effective average pressure on the head of the pile during its motion? (*d*) If the pile is driven only a very short distance (or is not noticeably moved) can you estimate the force or pressure? (*e*) In general terms, compare the effect of the stroke of a monkey of, say 4 cwt., falling 14 feet, with that of the monkey and fall given above. (B.E., H.B., 1903.)

12. A public building 50 feet wide from front to back, with a forecourt 10 feet in width, is to be constructed on a sloping site of slippery clay adjoining a public road, the level of the ground at the outer line of the rearwall of the building being 30 feet below the roadway at the front boundary, and the ground floor line 1 foot above the roadway. The building is to have a corridor 8 feet wide dividing the front and back rooms, and was to consist of a lower basement 10 feet high for the rear portion only, an upper basement over the whole, 10 feet high; also ground and first floors each 14 feet high, and second floor 10 feet high, all heights being in the clear. The frontage of the building to be 100 feet, and the central part of it, 15 feet wide, projecting 3 feet from the front line, is to be carried up as a tower two storeys above the remainder. Draw to

scale of 8 feet to 1 inch basement plan and transverse section of the building, showing the thicknesses of the walls, methods adopted for securing dryness and light in the lower floors, and solidity of foundations, consistent with economy in cost. The footings, etc., of flank wall and tower to be shown by dotted lines on the section.

(R.I.B.A., 1900.)

BRICKWORK.

13. What precautions should be taken to avoid failure and ensure good work in brickwork? What are the chief characteristics of good brickwork? Name twelve different kinds of bricks with which you are acquainted, and the uses for which each is most suitable. (R.I.B.A., 1900.)

14. Draw plans showing the arrangement of the bricks in two successive courses, at the square angle of a 1½-brick wall built in single Flemish bond. Scale 1 inch to a foot. Give reasons for the use of single Flemish bond. (C.G., 1903.)

15. Two external 18-inch brick walls meet at an angle of 60 degrees. Draw to a scale of 1 inch to the foot, the plan of two courses, in English bond, 3 feet each way from the quoin. (W.O.S., 1896.)

16. Give a plan, to a scale of $\frac{1}{12}$, showing the arrangement of the bricks in two successive courses at the angle of a building, the walls being 2½ bricks thick and built in English bond. The bricks in the lower course to be dotted in, and any joints running unbroken down the body of the wall to be shown by thick lines. Give a similar plan, supposing the wall to be built in single Flemish bond. Draw out a specification for the brickwork in the latter case using cement mortar, and red facings. (B.E., H.B., 1899.)

17. A bay of solid 18-inch brickwork, forming three sides of an octagon, is to be projected from an 18-inch wall. Draw plans of two courses in English bond, to a scale of $\frac{1}{12}$, showing one of the sides, about 3 feet 6 inches long, and the angles which it makes with the wall and the front of the bay, including the cut bricks necessary to form the angles. (B.E., H.B., 1900.)

18. Give sketches of (*a*) four wall-ties or bonding bricks for hollow walls, (*b*) four mortar joints, (*c*) herring-bone and diagonal bond, stating the purpose of the two latter,

(*d*) tile creasing, (*e*) Dentil work, (*f*) toothing and racking back. (C.G., 1903.)

19. Give section through the base of a hollow wall and for at least 5 feet above the ground, showing every detail of construction. (W.O.S., 1891.)

20. Given the front of an old building, which is to be pointed with a white tuck joint upon chocolate brown stopping. Give a specification for carrying out the work, the method of preparing the materials, and the quantity of pointing. (C.G., 1903.)

21. Describe three of the best methods, in your opinion, of forming damp-proof courses in the walls of dwelling-houses. Show, by sketches, how you would prevent the damp rising in the case of the walls of a building with a half basement, as well as without any basement. Show the floor level in each case. (B.E., A.B., 1900.)

22. Show by drawings, and describe, the mode of forming an opening for a shop front in the wall of an old dwelling-house that has two windows on each storey. All temporary strutting, shoring, etc., to be shown, as well as the bressummer and the means of its permanent support. (B.E., H.B., 1900.)

23. Draw, to a scale of 1½ inches to a foot, the plan of a window opening, showing how the bricks are laid in two successive courses in English bond, one course on each side of the opening. (C.G., 1903.)

24. Show clearly by a perspective or isometric freehand sketch three or four bays of a secure bricklayers' scaffolding at the corner of a building; the wall has reached about the middle of the second storey. Supply reference letters, and name and describe the various pieces. (B.E., A.B., 1901.)

25. Draw the section of the side wall of a house, showing floor levels, etc. It is found necessary to shore the wall from the second floor downwards. Show how you would do this by means of raking shores, and give explanatory details. State which you consider to be the most effective, raking or flying shores, giving reasons for your answer. (C.G., 1903.)

26. Sketch the best method of shoring the front wall of a building 60 feet high, so as to interfere with the street passenger

and wheel traffic as little as possible. Figure the scantling of the timbers. (W.O.S., 1898.)

27. A ground floor shop is to be enlarged by adding to it an adjoining shop, without disturbing the business more than is inevitable. This entails removing a 14-inch party wall, 25 feet long, and carrying the wall above on a wrought-iron girder supported by a cast-iron stanchion at each end, and a central cast-iron column standing on the party wall below the floor line of shop. Describe, and illustrate by sketches, how you would get the girder and its supports into position. Neither of the shop floors can be used for carrying temporary supports. The floors immediately above the shops are carried independently of the party wall. (B.E., H.B., 1899.)

28. Give a list of the various pavings used in buildings, the uses for which each is best suited and the defects each is liable to. (R.I.B.A., 1902.)

DRAINS.

29. What is the difference between earthenware and stoneware drain pipes? How would you distinguish them? What are their respective merits or demerits? (W.O.S., 1898.)

30. Describe three or more methods of joining earthenware or stoneware drain pipes. (W.O.S., 1898.)

31. Sketch an oval sewer 4 feet 6 inches deep, to be built in sand; give dimension, and state material. (W.O.S., 1898.)

32. Describe how you would test earthenware drain pipes. Sketch a drain pipe, giving the names and sizes of the different parts. (C.G., 1903.)

33. In excavating for a sewer, the bottom of the invert of which is 12 feet below road level, it is found necessary to pass through 3 feet 6 inches of made-up ground before reaching good ground. Draw to a scale of ½ inch to a foot, a plan of the timbering you would use for the excavation, giving the names and sizes of the different timbers. Also give a cross-section showing upon one half of a centre line half the section of the finished egg-shaped sewer, having an internal height of 3 feet 9 inches, and upon the other half the timbering. (C.G., 1903.)

34. State the nature and the proportions of the materials for a concrete sewer, and the test you would apply to secure strength. (M.E., 1902.)

35. Describe how you would proceed to ascertain if the drainage works to a dwelling-house were properly carried out, (*a*) before the trenches were filled in; and (*b*) upon completion. Assume a system of drainage such as you would yourself adopt. (R.I.B.A., 1900.)

36. Show by drawings, and clearly describe, how you would carry the drainage of a house in a row, where it has to pass under its basement floor, towards the sewer in the street; also how you would carry it if the pipes had to be kept 3 feet above the basement floor. Describe the pipes and joints in both cases, and all details necessary for proper inspection and ventilation. Explain the best mode of testing a pipe drain for leakage at joints, and for escape of foul air. (B.E., H.B., 1899.)

37. A sewer has to be laid through quicksand overlying coarse gravel; how would you proceed with the work? What precautions should be taken to ensure its permanent stability? (W.O.S., 1900.)

38. State the formula for determining the flow in an oval sewer, and state the minimum fall that should be given under certain conditions to be named. (W.O.S., 1898.)

39. What is the minimum inclination you would allow for a 6-inch house drain? and at that inclination what would be the velocity when the pipe was running full or half full? (W.O.S., 1898.)

40. What gradient would be necessary in 4, 6 and 9-inch pipe to ensure self-cleaning? (M.E., 1902.)

41. A dwelling-house is to be erected on damp subsoil; describe in detail the necessary works to render it dry and healthy. (M.E., 1902.)

42. What are considered self-cleansing velocities in sewers of small and large diameters respectively? When does a circular pipe discharge its greatest volume? (M.E., 1902.)

43. Draw up a short specification of an egg-shaped sewer, 4 ft. by 2 ft. 8 in., including the materials to be used, and the manner of its construction under a road, the invert being 30 feet below the road level. (W.O.S., 1896.)

44. Draw, to a scale of ½ inch to the foot, the section of an egg-shaped brick sewer. The intreme internal dimensions to be 4 ft. × 2 ft. 8 in. (W.O.S., 1896.)

45. Explain the terms "hydraulic mean depth" and "wetted perimeter" and their relation to each other. (M.E., 1902.)

46. Draw the outline of a portion of a building and the direction of a public sewer, F, near it. Show by neat sketches how you would propose to execute drainage to serve the following wastes: water-closet soil-pipe; the bath waste; the down spouting; scullery waste; pantry waste. Give such short explanations as you think are needed. State shortly what you think is the whole duty of house drains. (B.E., H.B., 1902.)

47. Draw, to a quarter scale in single outline only, the basement plan for a town house at the corner of a street, having open areas at front and side and containing kitchen, scullery, butler's pantry, housekeeper's room, servants' hall, w.c., etc. Show what you would consider to be the most perfect system of drainage, assuming that the sewer is in front of the house, also that there is a w.c. with lavatory on the ground floor and a bath lavatory and w.c. on the first and second floors. Mark on plan sizes of all pipes and state of what they are composed, how jointed, and what would in your opinion be the least fall that they should have. (R.I.B.A., 1902.)

48. A country house can only be drained by means of a cesspool the liquid contents of which will from time to time be pumped out. What precautionary measures should be taken to prevent contamination of the air of the house by foul air from the cesspool, to prevent nuisance from the escape of cesspool air into the atmosphere near to the house, and to prevent contamination of any well? Give sketches showing construction of cesspool with all traps and ventilation openings connected with the system. (B.E., H.B., 1900.)

MASONRY.

49. The stone wall of a warehouse has to be built on the edge of a tidal river, the site of which is covered at high tide by 2 feet of water. Show by sketches what steps you would take in order to carry out the work, and to ensure that the building shall be free from damp. (C.G., 1902.)

50. Draw, to a scale of 1½ inches to a foot, portion of plan and elevation, and the section of a stone sill 12 in. by

6 in., showing it sunk, weathered, moulded, throated and grooved for water bar. Projection from wall 4 inches. State how it should be bedded, and why. (C.G., 1902.)

51. Sketch and describe a mason's lewis for lifting heavy stones. (W.O.S., 1891.)

52. Draw to a scale of 4 feet to an inch half the elevation, half the section, and two half-plans of an octagonal broached spire constructed of stone upon a square stone tower, 14 feet wide externally, with belfry windows. The jointing of the masonry to be shown. (R.I.B.A., 1900.)

53. The stone tower of a church is 25 feet square externally, and carries an octagonal spire. Show by a small sketch the general design of the spire and upper part of tower. Show by enlarged sketches of the interior, and by a section, how the sides of the spire that spring from the angles of the tower are carried; also show the junction of the hollow portion of the spire with the solid portion at top. (B.E., H.B., 1900.)

54. Draw plan of part of a stone stair, the steps being spandril or feather-edged, with moulded nosings, 7 inch risers, and 11 inch treads. Give a section to a scale of 1½ inches to a foot. Taking the landing as formed of two slabs of stone, give a section of the connecting joint. (B.E., A.B., 1899.)

55. Give, to a scale of 2 inches to a foot, a cross-section of an 11-in. by 6-in. spandril step with moulded nosing, showing how it is carried. To the same scale, draw the elevation of the free end. (C.G., 1902.)

56. Give a sketch elevation of part of a stone staircase suitable to the hall of an important public building. Also, to a scale of an inch to a foot, explanatory details of same, including a vertical cross-section of two steps and a landing, showing a joint in the latter. Draw up a brief specification for same. (B.E., H.B., 1899.)

57. Describe the mason's work in a solid stone staircase 4 feet wide to a 12-feet storey of a warehouse, assuming the opening for same has been formed by steel girders; the stonework to have bearings on the walls only; and give section of step. (R.I.B.A., 1900.)

58. In a rectangular stairway 20 ft. × 10 ft. place a good stone staircase, steps 4 feet long; height from floor to top

of top landing 15 feet. Draw plan and vertical section (scale $\frac{1}{48}$) through one flight, showing elevation of ends of steps of second flight; show at least 2 balusters. Draw, to a $\frac{1}{4}$ scale, section of handrail; show details of fastening of balusters both to steps and handrail.
(B.E., H.B., 1901.)

59. Sketch neatly to the scale of $\frac{1}{12}$, showing the mortar joints with double lines, the elevation of about 4 ft. × 4 ft. of snecked rubble wall; give also the top of the sample in plan. How many bushels of sand and of lime, and what weight of "stock" (stone) approximately, is needed per cubic yard for this masonry?—the wall is 18 inches thick. (B.E., A.B., 1902.)

60. A wall is being built in coursed rubble; the stone is irregular fragments of granite, or trap, or any stone which fractures without much regard to "natural bed." Sketch two 12-inch courses in elevation, of such a wall for say 4 feet long, scale $\frac{1}{8}$; put numbers 1, 2, 3, etc., on the stones of the top course, showing the order in which a mason working from the left towards the right would set them. The mason speaks of the "bed" and the "face" of such stones. What does he mean? What is "rock-faced" work? What is a "shiner"? (B.E., A.B., 1901.)

61. Draw, to a scale of 1 inch to a foot, the section of a rubble wall 20 inches thick, showing the footings, damp course, a dry area, and the method of ventilating the space under the wooden floor. (C.G., 1902.)

62. A building 44 ft. × 22 ft. with brick walls faced internally with stone is to be covered with stone vaulting at a height of 15 feet from the floor line to the springing. No other supports than the walls are to be provided. The roof over is to be constructed with steel and concrete and to be covered externally with copper sheets upon coke breeze concrete. Give plan and section, drawn to a scale of 4 feet to 1 inch. (R.I.B.A., 1902.)

63. In towns where ashlar masonry is common the lintels to window and door openings, though of excellent stone, are seen to be in very many cases broken across; explain the cause of this. How might this fracture of lintels be prevented? (B.E., A.B., 1903.)

64. Draw to a scale of $\frac{3}{4}$ inch to a foot, a piece of elevation 6 ft. by 5 ft. of an ashlar wall, with a heavy rock-faced quoin. State how you would keep the work plumb. (C.G., 1902.)

65. Draw a sketch elevation of a stone gable, having a pitch of 60 degrees, with flat coping on one side and saddleback on the other. Show the best method of securing both. (C.G., 1902.)

66. Draw, to a scale of $1\frac{1}{2}$ inches to a foot, four different forms of stone copings to parapet walls. Describe the various methods of securing the stones and the materials used. (C.G., 1903.)

67. Draw, one quarter full size, the mullion and transom of a stone window, to a country house, with an iron casement in the upper light. Show the construction both by plan and section. (C.G., 1903.)

68. Draw, to a scale of $1\frac{1}{2}$ inches to a foot, half plan and half section of a stone cupola, 6 feet in diameter and 9 inches thick. Show the jointing, and the method of obtaining the moulds. (C.G., 1902.)

WALLS.

69. What is meant by saying that the height to which a pyramid of any building material may be raised is three times the height of a column of uniform section? Show how, by attending to a cardinal principle of construction, you can build a tower of brick or stone of very great height. (B.E., H.B., 1901.)

70. Sketch the section of an earthen reservoir dam to carry a head of water of 30 feet, giving approximate dimensions, and showing how the dam is to be made watertight—rock being 10 feet below the ground surface. (W.O.S., 1898.)

71. Sketch a retaining wall 12 feet high, the face having a batter of 1 in 12, suitable for retaining sand, and show the forces which keep it in equilibrium. (W.O.S., 1900.)

72. What pressure per square foot would you allow on the base of a pier in the middle of a building which has to carry the weight of the floors, when the substratum is (*a*) blue clay, (*b*) compact gravel, (*c*) sand? (W.O.S., 1898.)

73. If we take 8 tons per square foot as the safe load on a course of brickwork, and 120 lbs. as the weight of a cubic foot of brickwork, neglecting any question of wind pressure, to what height may a pyramid of brickwork be safely built? What is the duty supposed to be performed by bonding in this structure? (B.E., A.B., 1901.)

74. A rectangular wall, 10 feet high, has to resist a thrust of 500 lbs. per foot run, applied at an angle of 60 degrees to the horizon, at a height of 8 feet above the ground level. Taking the weight of the wall at 100 lbs. per foot cube. what must be its thickness, supposing it to be unstable, without taking into consideration the strength of the mortar? (B.E., H.B., 1899.)

75. A square mill chimney is 3,000 tons in weight: it is so bonded and built that it may be taken, under the conditions of the question, as one homogeneous mass. Its bottom bed is square, 30 ft. × 30 ft. with a 6 ft. × 6 ft. flue in the centre. Taking the force of the wind at 50 lbs. per square foot on an area of 3,000 square feet (centre of gravity of area 60 feet up) blowing at right angles to side of bed: batter of side of chimney $1\frac{1}{2}$ inches to 1 foot: find (*a*) maximum pressure per square foot at lee edge of bottom bed, (*b*) minimum pressure per square foot at windward edge, and (*c*) the total pressure on the bed. (B.E., H.B., 1901.)

76. A brick wall is 10 feet high, it is $13\frac{3}{4}$ inches thick, it may be taken as resting, without adhesion, on a horizontal bed at the ground level, and on which it bears uniformly. Assuming its weight to be 120 lbs. per cubic foot, and that its safe load (for crushing) is 8 tons per square foot, what wind pressure per square foot will it safely bear? Sketch a vertical cross-section and show the centre of pressure on the bed which will accord with the assumption of a maximum pressure of 8 tons per square foot. (B.E., H.B., 1902.)

77. The reservoir (for distribution) of the waterworks of a small town is a circular cylinder, 30 feet high and 20 feet in diameter. When the cylinder is full of water, what is the tensional stress in a ring of the cylinder 1 foot wide (or deep), whose centre line is at the height of 1 foot 6 inches

from the bottom? What should be the thickness of iron plate to *safely* sustain this stress?

(B.E., H.B., 1903.)

78. A brick tower of efficient design is built on a square base 60 ft. × 60 ft.: it is 500 feet high. Allowing 6 tons per square foot as the *safe* load on a cross-section, and taking 120 lbs. as the weight of a cubic foot of brickwork, what is the area of the top? What weight in tons may be safely placed on the top? Given: log. 111 = 2·04532, log. 112 = 2·04921, log. 4086 = 3·61130, and log. 36 = 1·55630. You may assume 1 foot courses.

(B.E., H.B., 1901.)

79. Describe and illustrate by sketches the various methods of building walls in exposed positions for the purpose of excluding driving rain. What precautions have to be taken in the construction of openings and quoins where these methods are employed? (C.G., 1903.)

80. Draw a cross-section of an embankment 50 feet high to an open reservoir showing a puddle wall, and figure the inside and outside slope. (M.E., 1902.)

ARCHES.

81. Give sketches of a springer or skew corbel, kneeler, vertical dowel or bed plug, and a label to an external arch of a Gothic window. (C.G., 1903.)

82. Draw to a scale of 1 inch to a foot, the elevation of a gauged camber arch, 14 inches on the face, and for a 4-feet opening. Why, in practice, is the arch cambered, and how would you obtain the camber slip? (C.G., 1903.)

83. Draw the elevation of a window opening. Upon the left-hand side of the centre line show the construction of a brick relieving or discharging arch in two half-brick rings, and on the right-hand side a gauged segmental arch, 9 inches on the face. Each arch is to have a rise of 9 inches. Scale 1 inch to a foot. (C.G., 1903.)

84. Sketch the centre to be used in building a brick circular arch of 15 feet span, and describe the method of easing same.

(W.O.S., 1898.)

85. Draw, to a scale of 1 inch to a foot, the elevation of a semi-circular arch, 10 inches on the face, for a 6-feet opening,

showing the voussoirs stepped out to meet the bed joints of the surrounding ashlar which is built in 10 inch courses. (C.G., 1903.)

86. Sketch any voussoir of a segmental arch, and show the forces which keep it in equilibrium. (W.O.S., 1900.)

87. What is meant by the "principle of least resistance," and how is it applied to the investigation of the stability of arches? (W.O.S., 1896.)

88. Sketch the longitudinal section through the end arch of a brick bridge of 60 feet span to carry a roadway, showing the abutment and first pier: the arch to be elliptic, the soffit being 30 feet above ground level, and the substratum being compact gravel and sand. (W.O.S., 1898.)

89. A railway is carried over a common road on a masonry arch; the centre line of the railway makes an angle of 60 degrees with the centre line of the road; the width of the road is 24 feet; the arch is segmental (at right angles to the centre line of the road) having a rise of 9 feet. Draw the half elevation of one face, showing the obtuse angle of an abutment, and showing the joints in the half ring. In what respects do these ring joints differ from the ring joints of a direct elliptical arch when they are drawn as normals to the intrados curve? Show how you draw normals to an ellipse. Describe what you understand by a coursing helix in the sheeting of a skew arch. (B.E., A.B., 1902.)

FLUES, FIREPLACES, TALL CHIMNEYS, ETC.

90. Draw to a scale of ½ inch to a foot, the plan and elevation of a chimney stack of two flues, showing the jointing. The flues to be 9 inches by 9 inches, and the height of the stack 6 feet. (C.G., 1902.)

91. Draw the section of a cavity wall, to a scale of 1½ inches to a foot, making any arrangement you consider necessary, and stating against your drawing the object of such a wall. If you were building the wall, how would you keep the cavity clear of mortar? (C.G., 1903.)

92. Draw plans of the successive courses of a chimney stack, showing the arrangement of the bricks laid in Flemish bond. Scale 1 inch to a foot. What is the minimum height a chimney stack or flue should be carried above the roof? (C.G., 1903.)

93. Four detached flues, each about 80 inches in sectional area, are to be placed near each other so as to form a stack of brick chimneys, rising 14 feet above the tile ridge of roof. Show by plans and sections, to a scale of 8 feet to an inch, a wall 14 inches thick on the upper floor of a house, with a fireplace on each side of the wall, and two flues from a lower floor; show also the flues rising to the above-named stack through the roofs and surrounding parts. Also give plan of the stack near the top to a scale of 2 feet to an inch. (R.I.B.A., 1900.)

94. Draw to a scale of 4 feet to 1 inch two plans and a section of a chimney breast with chimney stack over it at the upper part of a three-storey building. Five flues to be provided, arranged in two rows, one being the flue of a furnace for heating apparatus. The fireplace to be for a kitchen and to be 4 feet wide with brick trimmer arch and stone hearth. A fir-framed roof truss for a span of 25 feet to have a bearing upon the chimney breast over the centre line of fireplace, and to be so arranged as to avoid any fire risk. (R.I.B.A., 1902.)

95. Draw (*a*) the elevation, (*b*) a vertical cross-section at the centre, and (*c*) a half horizontal cross-section (just over the grate) of a good register grate fireplace, to the scale of $\frac{1}{8}$. How is the fireblock back to be renewed? How is the chimney to be swept and the soot cleared away? (B.E., A.B., 1903.)

96. Design a fireplace, grate, mantel, and overmantel and cornice in a drawing-room. Height of ceiling from floor 13 feet. Sketch so much of each proposed separate detail as may be necessary to show accurately what is intended at every part of the work. These sketches should be very neatly done. (B.E., H.B., 1902.)

97. Explain and illustrate by sketches how you would set the kitchen range shown. Show the flues; show by a diagram the connections between the boot boiler and

the hot-water cocks in scullery, bathroom, etc. Why is a safety valve needed? Show where it may be placed.
(B.E., A.B., 1902.)

98. A square chimney 100 feet high, 6 feet wide at the base, and 4 feet wide at the top, has to withstand a wind pressure of 56 lbs. per square foot; what must be the average thickness of the brickwork, assuming the chimney to be simply resting upon and not attached to its base? Assume the bricks to weigh 120 lbs. per cubic foot.
(W.O.S., 1900.)

99. Draw the plan of a fireplace opening upon an upper floor, there being no projection beyond the 13½ inches in the rooms below. Give a vertical cross-section on the line A—B, showing how the front and back hearths, jambs, etc., are carried. Scale 1 inch to a foot.
(C.G., 1903.)

100. Draw the plan of a fireplace opening 3 feet high. Draw the elevation, to a scale of 1 inch to a foot, showing a rough arch, chimney bar, and the direction of the flue, by dotted lines, to a height of 5 feet above the opening. To the same scale give a vertical section through A—B. The joints of the bricks need not be filled in. State, in your own words, any byelaw with which you are acquainted, governing the thickness, etc., of the fireplace back.
(C.G., 1903.)

LIMES AND CEMENTS.

101. For what purpose is sand added to lime in the preparation of mortar? (W.O.S., 1900.)

102. Give reasons for using sand with limes and cements, and state which you consider to be the best sand for building purposes. Name at least two substitutes for sand, stating the advantages and disadvantages of each. In making mortar from grey stone and blue lias limes respectively, what proportion of sand would you use to obtain the maximum strength, and why? (C.G., 1903.)

103 Why are rich limes slaked before use? (W.O.S., 1900)

104. State briefly the difference between Roman and Portland cement, as regards manufacture, colour, weight, setting properties and ultimate strength. (B.E., A.B., 1900.)

105. Which is best for mortar, white or grey chalk lime? Give reasons. (W.O.S., 1891.)

106. How are the qualities of mortar affected by the admixture of (1) too much sand, (2) too little sand, (3) ground bricks, (4) old mortar, (5) plaster of Paris, respectively? Give the chemical and other reasons for the facts you state. (W.O.S., 1896.)

107. Give a description of the various materials used in the composition of lime and cement mortars, the principles upon which sand is added, and the proportion in which each material is used. (C.G., 1903.)

108. Describe the materials used for, with the proportions and mode cf mixing, lime mortar. Mention two well-known varieties of lime, one being suitable for use in wet ground; also a lime that is unsuitable for use in brickwork, with the reasons in each case. Describe the kind of sand most suitable for mortar. (B.E., H.B., 1900.)

109. Describe carefully the preparation of plaster of Paris. In what respects does plaster of Paris differ from the gypsum from which it is made? (B.E., H.B., 1903.)

110. Describe carefully the composition of good Portland cement, and explain fully its manufacture. Specify good Portland cement, and explain minutely how it should be tested. (B.E., H.B., 1903.)

111. How is Roman cement made? What are its properties? For what purposes is it generally used? (W.O.S., 1900.)

112. What are:—Portland cement, Roman cement, Keene's cement, Medina cement? State what you know of the manufacture and properties of good Portland cement. What would you specify as the conditions to be fulfilled by good Portland cement? How would you perform the tests? (B.E., A.B., 1901.)

113. Explain why the sand for mortar should be clean, sharp sand, free from clay. What is a hydraulic lime, and in what respects does it differ from rich or fat lime? Portland cement is made from lime and clay; explain the difference between Portland cement mortar and common lime mortar to which clay is added. (B.E., A.B., 1902.)

114. What is quicklime, and how is it produced? Use such terms as you think would be intelligible to a workman, familiar with the handling of lime and plaster of Paris, and describe—(*a*) what happens when water is applied to quicklime; (*b*) what happens when plaster of Paris is mixed with water—to be used for casts: giving the best rational explanation you can of the actions.

(B.E., A.B., 1903.)

115. Give sketches showing the difference between flare and tunnel kilns for lime burning. State how they are worked, and their relative merits. What are Parian and Keene's cements used for, and under what circumstances would you select one in preference to the other?

(B.E., H.B., 1899.)

116. (*a*) Describe a lime-kiln—illustrate with sketches. Describe the preparation of limestone for burning. (*b*) Given—Ca 40, O 16, C 12; what weight of lime should result from a charge of 4 tons of limestone? The weight of limestone is made up of 3·424 tons of $Ca\ CO^3$ + ·4 ton of a substance not altered in weight by the burning, + ·176 ton of water which is driven off. (*c*) How many cwt. of coals (approximately) are required to burn 4 tons of limestone to lime? (B.E., H.B., 1903.)

CONCRETE.

117. What materials are employed in making concrete for building a concrete house, and what precautions have to be taken to prevent the walls cracking?

(R.I.B.A., 1900.)

118. Which of the following materials is most suitable for use as an aggregate in Portland cement concrete where great strength is required, viz.:—Blue Guernsey granite, Bath stone, blue Staffordshire bricks, Portland stone, broken fireclay pipes? Place these aggregates in their order of merit and give the reasons for your selection.

(W.O.S., 1900.)

119. What proportions of cement, sand, and broken brick or stone would you specify for concrete for—(*a*) foundations for main walls, (*b*) concrete stair landings, (*c*) water-tight work. (M.E., 1902.)

120. What is a ground layer? Do you consider concrete, as a ground layer, to be impervious? What steps would you take to prevent damp rising through a basement floor of concrete 6 inches thick? (C.G., 1903.)

BRICKS, TERRA COTTA AND STONEWARE.

121. What are:—stock bricks; malms; purpose mades; place bricks? In selecting the best bricks from a heap, they are taken up in pairs and thrown to a second man; the work is done rapidly; what instructions would you give to the man picking up the bricks to ensure that the second man receives picked bricks? Bricks from the same kiln differ by greater amounts in one dimension than in either of the other dimensions; which dimension is this, and why? (B.E., A.B., 1901.)

122. If it is an advantage to have wide joints for brickwork, built with Portland cement mortar, what change in the dimensions of the bricks is desirable for such work? What tests should be applied to a particular make of bricks, proposed to be used in important exposed work and built with cement mortar? What are fire-bricks, and how do they differ from common bricks? (B.E., A.B., 1902.)

123. What bricks are suitable material for paving a wash-house? Would you set them in cement, or ordinary mortar? Give reasons. (W.O.S., 1896.)

124. Describe the complete operation of brickmaking. Candidates who have experience of the actual operation, should answer from their direct observation, as far as possible. (B.E., H.B., 1902.)

125. Describe the difference between kiln and clamp burnt bricks. (W.O.S., 1891.)

126. Describe the characteristics of (*a*) salt glazed bricks; (*b*) dipped salt glazed bricks; (*c*) glazed or enamelled bricks; (*d*) adamantine clinkers. How many of the latter would pave a space 9 feet by 4 feet? (C.G., 1903.)

127. What is the safe load on piers built of stock bricks, in (*a*) Portland cement and sand, 1 to 1; (*b*) blue lias lime and sand, 1 to 2; (*c*) grey stone lime and sand, 1 to 3. What is the standard proportion of the height of piers to their thickness? (C.G., 1903.)

128. Sketch a sectional plan and a sectional elevation of a Hoffmann kiln. Explain, referring to your sketches, the scientific principle of the kiln and describe the practical working of it. (B.E., H.B., 1901.)

129. Describe any brick-making machine with which you are acquainted. What is the meaning of the terms "pressed bricks" and "wire cuts"? (C.G., 1903.)

130. What is terra cotta? How is it manufactured? What are its principal uses in building? (W.O.S., 1900.)

131. What are the methods of preparing terra cotta? What materials are used for filling the blocks and setting the work? What are the advantages or disadvantages of terra cotta compared with stone? (C.G., 1903.)

STONES.

132. Under what circumstances is a stone laid otherwise than on its natural bed, and for what reasons? How would you ascertain the natural bed of a stone? How should window sills be bedded, and why? (C.G., 1903.)

133. In a tabulated form, give the following particulars of six building stones:—Situation of quarry, geological formation, colour and appearance, method of working, weight per foot cube, crushingweight. (C.G., 1903.)

134. What is quarry sap, how does it affect the working? (W.O.S., 1900.)

135. A certain building of Mansfield stone was disfigured by efflorescence, which spread 2 inches on each side of all the joints. What do you consider this was caused through, and what precautions would you take to prevent its occurrence? (C.G., 1902.)

136. Give a list of stones used in buildings for the following purposes:—(i.) walling; (ii.) dressings; (iii.) steps and landings; (iv.) internal work in churches (3 stones in each division). Describe the tests you would apply to each kind and the finish you would give to the surface of each kind. (R.I.B.A., 1900.)

137. Name some of the best known building stones, and state the purposes for which each kind of stone is most suitable. (W.O.S., 1898.)

138. In selecting roofing slates, would you give preference to a thick or thin slate? How many Welsh roofing slates, best seconds, 20 in. × 10 in. placed flat would rise 12 inches? (W.O.S., 1898.)

139. Describe the quarrying of a good building stone. Give the geological formation to which it belongs, or name the quarry and give the general character of the stone. Sketch and describe the tools used. If the candidate has had opportunity to see actual quarrying, he should endeavour to describe what he has seen. (B.E., H.B., 1902.)

140. Sketch and describe six hard stone, and six soft stone, masons' tools, stating the purposes for which each is used. (C.G., 1902.)

141. Give an example of igneous and aqueous rocks used in building and state which are most useful to the builder. (W.O.S., 1900.)

142. What is broadly the composition of marble, and what types, if any, are suitable for external use. (R.I.B.A., 1902.)

143. To what class of building stones does marble belong? To what does it owe its figuring, if any? (C.G., 1903.)

144. State what you know about the different kinds of Portland stone. (W.O.S., 1891.)

145. Give three different processes for preserving stone, and the means of application. (C.G., 1903.)

146. State briefly what the weathering properties of sandstones and slates chiefly depend on, and describe any rough methods of testing the same you may be acquainted with. (B.E., A.B., 1900.)

147. State briefly on what the weathering properties of granites, sandstones, and slates depend, and how you would, in a rough way, judge as to their durability. Name one or two well-known varieties in each case, and mention their special characteristics. (B.E., H.B., 1899.)

148. How do magnesian limestones differ from those that are not magnesian, and crystalline limestones from non-crystalline, in their qualities as building materials, and as sources of lime? Illustrate your answer by reference to the stones from definite localities. (W.O.S., 1896.)

149. What are the differences in the constituents of basalt, granite, clunch, Yorkshire mountain limestone, Yorkshire flag, Westmoreland blue flag, Yorkshire millstone, Portland, Purbeck marble, and which should be placed on their natural beds and why? (W.O.S., 1891.)

150. Describe the mineralogical characters of felspar, talc, and gypsum; and show, by examples, the influence they have on the qualities of the rocks of which they are constituents. (W.O.S., 1896.)

151. By what characteristics would you distinguish the following: Talc, fluorspar, felspar, hornblende, obsidian? (W.O.S., 1891.)

QUANTITIES AND ESTIMATING.

152. How many London stock bricks should a bricklayer set in lime mortar in an 18-inch boundary wall not exceeding 8 feet in height, per day of 10 hours? (W.O.S., 1898.)

153. How is brickwork usually measured in your district? How many bricks go to a foot of reduced work, London measurement? (C.G., 1903.)

154. Give the values of the following items in the form usual in your district:—(*a*) excavation to a depth not exceeding 4 feet in good ground and carting away; (*b*) common brickwork set in mortar to the outside wall of a house; (*c*) pavement of a playground in concrete and asphalte, and state thicknesses. (R.I.B.A., 1902.)

155. Take nine bushels of sand, and three bushels of Portland cement, and make it into mortar; how many bushels of mortar (approximately) will you have? If upright joints are $\frac{1}{2}$ inch thick, and the beds $\frac{7}{8}$ inch thick (allowing for the frog), how many courses of a two-brick wall 12 bricks long will this quantity build? The dimensions of bricks are 9 in. × $4\frac{1}{4}$ in. × 3 in. Will you use more mortar per cubic yard of brickwork in a two-brick wall than in a one-brick wall, and if so, how much more? (B.E., A.B., 1902.)

156. Bricks (9 in. × $4\frac{1}{4}$ in. × 3 in.) cost 35*s.* a thousand; Portland cement costs 3*s.* 6*d.* a bushel; sand costs $2\frac{1}{2}$*d.* a bushel (all as delivered on the works). What is the cost for these materials for a cubic yard of 2-brick wall

(mortar, 1 of cement to 3 of sand, joints to show ½ inch thick)? (21 bushels in a cubic yard.)

(B.E., A.B., 1903.)

157. Bricklayers' wages 1*s.* an hour, attendants' wages 6*d.* an hour; for plain brick walling 16 to 30 feet over ground; give a reasonable proportion between cost for bricklaying and cost for attendance. Including both items, what is a fair cost per cubic yard for workmanship? What other items of expenditure should be charged to the brickwork? Give reasons for your proportion and estimate.

(B.E., A.B., 1903.)

158. Write full instructions for a specification for a bridge of a single arch to carry a 20-feet roadway over a stream (the instructions should refer to the general conditions of the contract as well as to the actual works, but they are to be no more detailed than is necessary to enable an assistant to draw up the full specification). The centre line of the stream makes an angle of 60 degrees with that of the road; there is a good rock foundation at the level of the bed of the stream); abutments 6 feet high (to springing from rocky bed); span, at right angles to centre line of stream, 20 feet; arch segmental on cross-section, at right angles to the centre line of the stream, having a rise of 8 feet; banks of stream 6 feet over bed, 30 feet from bank to bank. The roads and fences are carried on filling, which slopes 1 to 1 to level top of river banks. The general work is to be masonry, built with Portland cement mortar, showing squared, uncoursed, wide-jointed rubble in faces. Copings to be thorough stones, not laid on a prepared continuous bed, but rising from the uncoursed masonry, chisel drafted along top corners and smooth dressed on top. The sheeting is to be of blue bricks in cement mortar. Make such sketches as will sufficiently direct your office assistant to make accurate drawings.

(B.E., H.B., 1902.)

159. Draft a specification for the supply of stoneware sewer pipes. (W.O.S., 1896.)

160. You have to carry a railway through a hill; the surface of the ground is 40 feet above the "formation" surface of the railway (that is, the surface which is prepared to

receive the ballast to sustain the sleepers); the total breadth of the formation and drains is 25 feet: the slopes in open cutting would be secure at 1 to 1; the ground is easy to get and to fill: you have to decide whether—(*a*) you will have an open cutting, with slopes the whole way down to the formation; (*b*) you will have an open cutting with revetment walls; (*c*) you will excavate a tunnel and line it with brickwork: describe in what way you will seek to come to a sound conclusion (the question is one of cost only). Sketch half cross-sections of (*a*) open cutting the full depth; (*b*) open cutting with revetment walls 10 feet high; (*c*) the tunnel: stone costs 3*s.* a ton, bricks 35*s.* a thousand, Portland cement 40*s.* a ton, sand 2½*d.* a bushel. Find the cost of a yard forward on each assumption. (B.E., H.B. 1903.)

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